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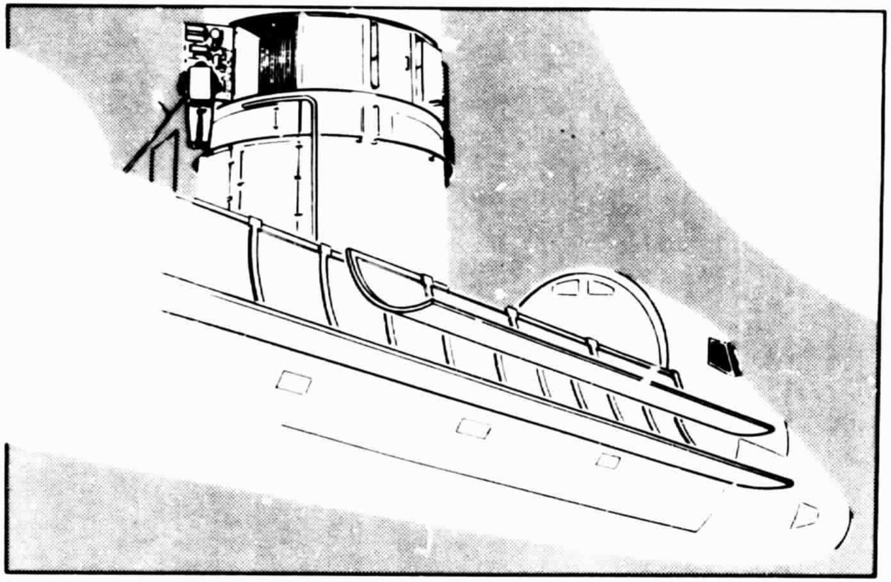
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058



Satellite Services Handbook

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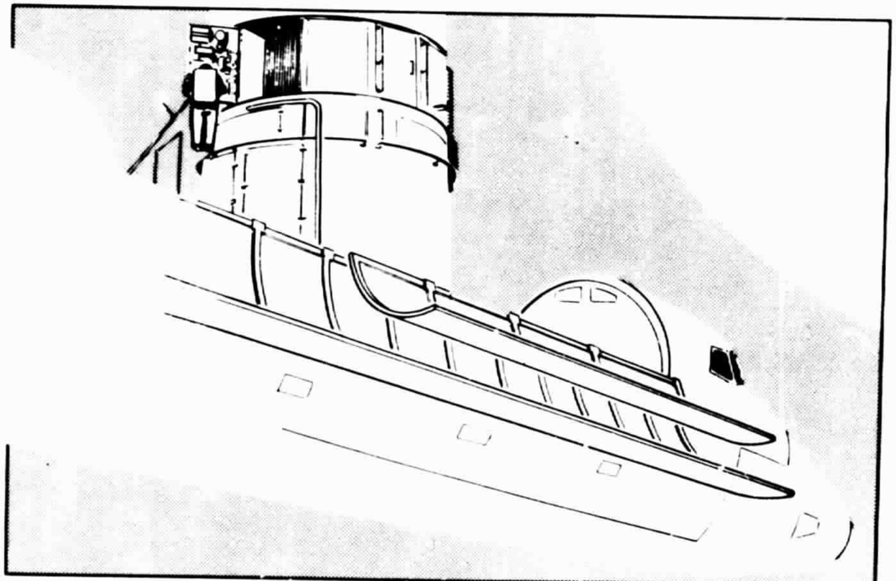

Satellite Services Handbook

INTERFACE GUIDELINES

CONTRACT NAS9-15800
23 DECEMBER 1983

PREPARED FOR: NASA/JSC
HOUSTON, TEXAS

Lockheed

FOREWORD

This handbook identifies satellite interfaces for on-orbit servicing, both manned and unmanned, and is intended to be used by designers of space vehicles, both foreign and domestic. A primary concern is for design of interfaces with the astronaut in the loop, especially extravehicular activity, but also intravehicular activity and operations that may be remote but have man-in-the-loop. The main emphasis of this document is on servicing in low earth orbits from the Space Shuttle and also from the Space Station or other platforms. Later releases will include remote servicing.

This volume is arranged in a format that facilitates future revision and expansion and gives quick and easy access to the data. The report was produced under NASA contract NAS9-15800. Corrections, comments, or relevant material suggested for inclusion in future editions should be sent to the NASA technical monitor:

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Houston, Texas 77058
Telephone: (713) 483-2954

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1.0 GENERAL GUIDELINES	1.4	1.2 1.4	1.2 1.4	1.2 1.3 1.4 1.6	1.2 1.4	1.2 1.4	1.2 1.4	1.2 1.4	1.2 1.4	1.1 1.3 1.4	1.2 1.4	1.2 1.4
2.0 DESIGN OF ORU'S	2.3 2.4	2.3 2.5	2.3 2.8	2.3 2.5	2.2 2.3	2.2 2.3	2.2 2.3	2.2 2.3	2.4	2.4 2.7	2.2 2.3	2.2 2.3
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SPACECRAFT HARDW

DATA MANAGEMENT UNITS	DATA RECORDERS	DECODER/ENCODER UNITS	DETECTORS	DIODE UNIT	DOORS/COVERS	EXPENDABLES	FINE GUIDANCE SENSORS	GAS/LIQUID TRANSFER LINES	HEATERS	INSTRUMENTATION UNIT	INTERFACE UNITS	LATCHING DEVICES	LIGHTS	LIGHT SHIELDS	MAGNET
1.2 1.4	1.2 1.4	1.2 1.4	1.2 1.4	1.2 1.4	1.3 1.4 1.6	1.3	1.2 1.4	1.3 1.4	1.2 1.3 1.4	1.2 1.4	1.2 1.4	1.3 1.4 1.6	1.2 1.3 1.4	1.2 1.4	1.2 1.4
2.2 2.3	2.2 2.3	2.2 2.3	2.2 2.3	2.2 2.3	2.4 2.6	2.4	2.3		2.5	2.2 2.8	2.2	2.4 2.6 2.7	2.3	2.3	2.2
3.2.1	3.2.1		3.2.1		3.2.6	3.1		3.2.3		3.2.1					
					4.2			4.2	4.2 4.3.5			4.2 4.3		4.35	
5.9	5.4 5.9	5.6 5.9	5.6 5.9	5.6 5.9	5.2 5.6 5.3 5.7 5.4 5.8 5.5	5.3 5.9	5.3 5.9	5.3 5.4	5.3 5.6 5.9	5.4 5.9	5.4 5.9	5.4 5.5 5.6 5.8	5.7	5.2 5.3 5.5 5.6	5.6 5.9
6.2	6.2	6.2	6.2	6.2	6.4 6.5					6.2	6.2	6.4 6.5	6.2	6.5	6.2
7.6	7.6	7.6	7.6	7.6	7.7	7.3	7.6	7.3	7.7	7.6	7.6	7.7	7.6 7.7	7.6 7.7	7.6

2 FOLDOUT FRAME

SERVICING GUIDELINE REFERENCE PARAGRAPH vs S

AFT HARDWARE ELEMENTS

GHT SHIELDS	MAGNETIC TORQUERS	MAGNETOMETERS	MULTI LAYER INSULATION	OPTICAL DEVICES	OVERRIDE MECHANISMS	PHOTO SENSING EQUIPMENT	POWER CONTROL UNITS	POWER DISTRIBUTION UNITS	PROTECTIVE DEVICES	RATE SENSOR UNITS	REACTION WHEELS	RECEIVER	SCIENTIFIC INSTRUMENTS	SOLAR ARRAYS	STAR TRACKE	T
	1.2 1.4	1.2 1.4	1.3 1.4 1.5	1.2 1.4	1.4 1.6	1.2 1.4	1.2 1.4	1.2 1.4	1.3 1.4	1.2 1.4	1.2 1.4	1.2 1.4	1.3 1.4	1.4	1.4	1.3 1.4
	2.2	2.3	2.13	2.3 2.5	2.4 2.7	2.3 2.5	2.2 2.3	2.2 λ.3		2.2 2.3	2.2 2.5	2.2 2.3	2.3 2.4	2.3 2.4 2.5	2.3 2.5	2.3 2.4 2.5
																3.2
5					4.3.5	4.3.5			4.2		4.2 4.3		4.3.5	4.2 4.3.5		4.3.5
	5.6 5.9	5.6	5.4	5.3	5.3 5.4 5.8	5.3 5.6 5.9	5.6 5.9	5.6 5.9	5.3 5.8 5.4 5.5 5.6	5.3 5.9	5.3 5.6 5.9	5.6 5.9	5.3 5.4 5.6 5.9	5.3 5.4 5.5 5.6	5.3 5.6	5.3 5.9
5	6.2				6.4 6.5	6.2	6.2	6.2		6.2				6.4 6.5		
5 7	7.6	7.6	7.6	7.6	7.7	7.6	7.6	7.6	7.7	7.6	7.6 7.7	7.6	7.2	7.2		

AGRAPH vs SPACECRAFT HARDWARE ELEMENTS

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	SCIENTIFIC INSTRUMENTS	SOLAR ARRAYS	STAR TRACKERS	TANKAGE	TAPE RECORDERS	TEMP. SENSORS	THERMAL SHIELDS	TRANSMITTER	TRANSPONDERS	UMBILICALS	WAVE GUIDE ASSY	WIRE HARNESSES	WORKSITES
	1.3 1.4	1.4	1.4	1.3 1.4	1.2 1.4	1.4	1.3 1.4	1.2 1.4	1.2 1.4	1.4	1.2 1.4 1.6	1.4	1.1 1.4
	2.3 2.4	2.3 2.4 2.5	2.3 2.5	2.3 2.4 2.5	2.2 2.3	2.3 2.13	2.3 2.13	2.3	2.3	2.8 2.9	2.3 2.5	2.8 2.9	2.7 2.11
				3.2		3.2.1	3.2.1			3.2.2 3.2.4		3.2.2 3.2.3 3.2.4	3.2.1 3.2.6
	4.3.5	4.2 4.3.5		4.3.5			4.2				4.2 4.3		
	5.3 5.4 5.6 5.9	5.3 5.4 5.5 5.6	5.3 5.6	5.3 5.9	5.3 5.9	5.6 5.9	5.3 5.5 5.6	5.9	5.6 5.9	5.3 5.4	5.6	5.3 5.4	5.2 5.8 5.4 5.5 5.7
		6.4 6.5			6.2			6.2	6.2	6.3			
	7.2	7.2			7.6		7.6	7.6	7.6	7.5	7.7	7.5	7.3 7.8 7.9

OVERVIEW

Satellite servicing will be dominated for the next several years by the application of Space Shuttle capabilities to such tasks as on-orbit satellite repair, replenishment, changeout, and recovery, with expansion to the use of other orbital maneuvering vehicles or space stations as they become available. This document emphasizes extravehicular manned activity, but also covers internal cabin operations and other more remote man-machine interfaces and activities. Future expansion of these design interface guidelines is expected to augment coverage of these other servicing interfaces and also will extend interface design factors for satellite servicing in high-altitude orbits. Universal adoption of these guidelines can improve safety, reduce technical risk, and economize on resources for accomplishment of on-orbit servicing.

Each major section of this document emphasizes functional requirements within its topical area and also includes design guidelines and applications for specific system features. A cross-reference matrix is included to improve access to data and to quickly locate coverage of desired topics. Section 1 gives general mechanical guidelines and approaches for hazard avoidance. Following sections provide design recommendations for orbital replaceable units (ORUs), resupply of consumables, design and operation of mechanical features, crew interfaces, support equipment, and crew safety. Concluding sections (training, simulation, facilities, software, operations, and the Space Transportation System) are covered only briefly in this initial report because good interface design definition is available in other documentation.

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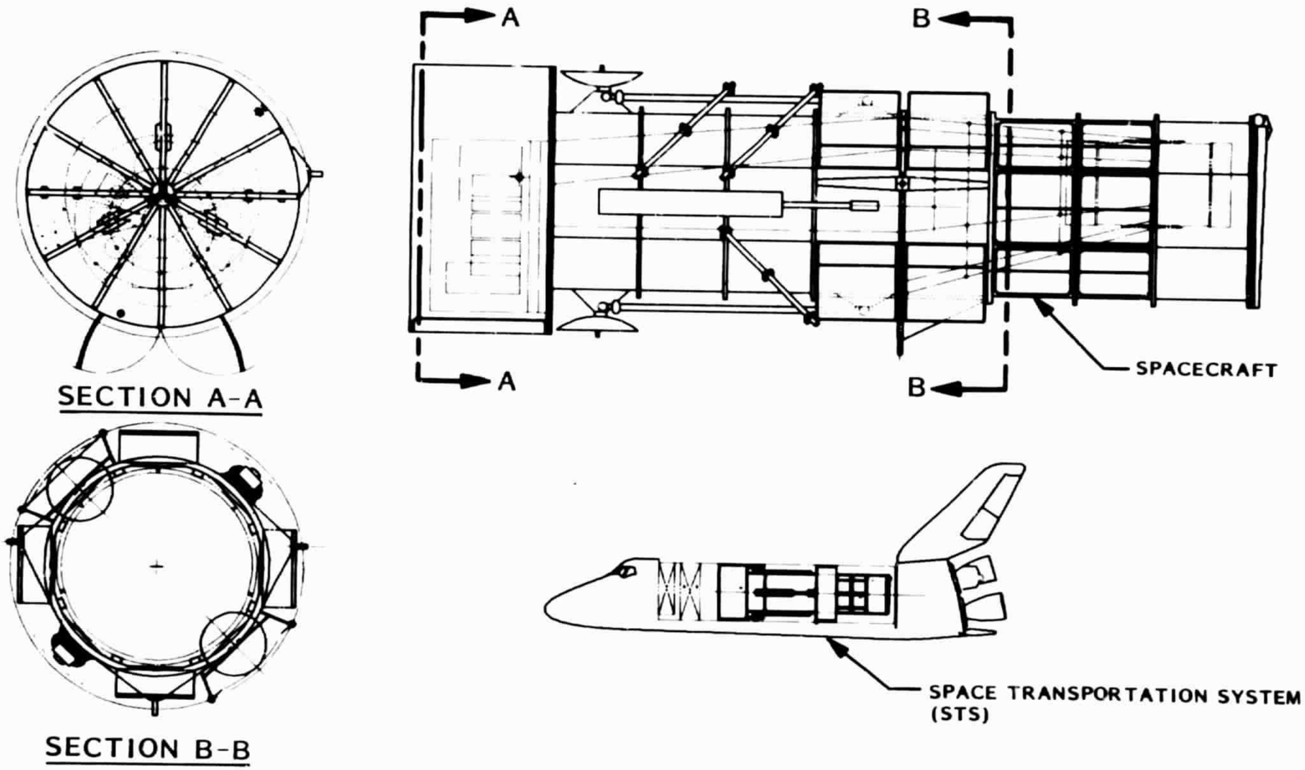
SECTION 1.0
GENERAL GUIDELINES



1.0 GENERAL GUIDELINES

1.1 General

Payload structures and related airborne support equipment (ASE) requiring an EV interface should be designed to maximize operational efficiency and eliminate potential failures and hazard risks to crewmembers. An EVA worksite for on-orbit maintenance is depicted in Fig. 1.1-1.

1.2 Structure Footprint

Consider the following guidelines when designing the interfaces of equipment to spacecraft structure.

1.2.1 The footprint of structurally mounted equipment (such as an orbital replaceable unit (ORU)) should be outlined with bright markings to facilitate placement of the ORU in its correct orientation and to reduce the collateral damage potential.

1.2.2 The footprint outline should be standardized relative to marking techniques and color coding.

1.2.3 The outline of the footprint should be marked on the structure so that it will surround the circumference of the ORU when mounting is complete.

1.2.4 An ORU should have a clear pathway provided for entry/exit from a footprint and, when possible, ORUs should be removed or replaced along a straight or slightly curved line.

1.2.5 Where applicable, keyed holes or slots in the footprint should allow a 0.125-inch clearance from the female to male mounting interface.

1.3 Structure - Openings/Access

When possible, openings or areas that require access

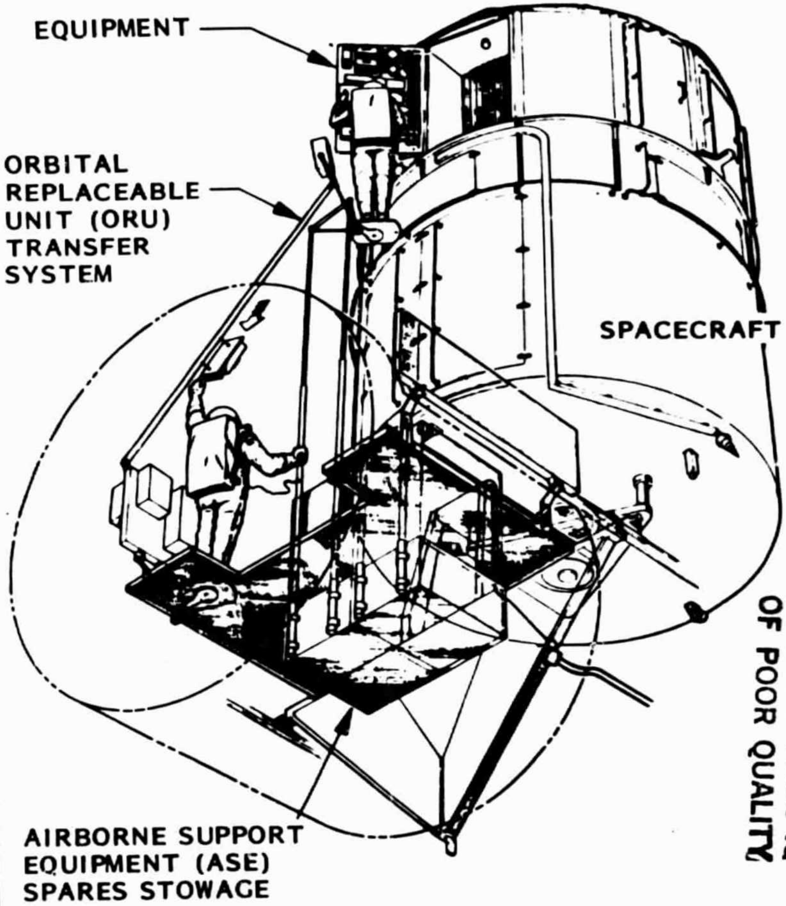


Fig. 1.1-1 Typical Satellite EV Servicing with Airborne Support Equipment

to the spacecraft structure should incorporate the following provisions.

1.3.1 Equipment should be mounted on the spacecraft structure to allow for gloved-hand tool access clearance.

1.3.2 Doorstops, tiedowns, and "keepers" used to hold access panels open should be mounted to allow volumetric access and operation by a single gloved hand.

1.3.3 The maximum force required to open/close an access door or panel should be 10 pounds.

1.3.4 A restraint (such as a magnetic latch) should be provided to temporarily hold access doors and panels open.

1.3.5 Warning or caution flags or indicators should be installed at access panels and doors to allow position statusing by the crewmember.

1.3.6 When a crewmember's entire body is required to pass through an access opening or hole, the following conditions should apply.

1.3.6.1 When translation through an access opening is made in a straight line, a 43-inch-diameter clear envelope should be provided.

1.3.6.2 When translation requires abrupt changes in direction (more than 30 deg in 9 feet), a minimum 48-inch-diameter clear envelope should be provided.

1.3.6.3 Spacecraft equipment sensitive to EVA/EMU effluent or scraped debris from the EMU suit should incorporate self-protective features (such as covers) or operational constraints should be imposed on EV crewmembers.

1.3.6.4 When possible, equipment that the crewmember could inadvertently damage should be designed to withstand the loads a crewmember might impose.

1.3.6.5 Corners, edges, and protrusions should meet the snag prevention and surface abrasion guidelines included in Section 1.4.

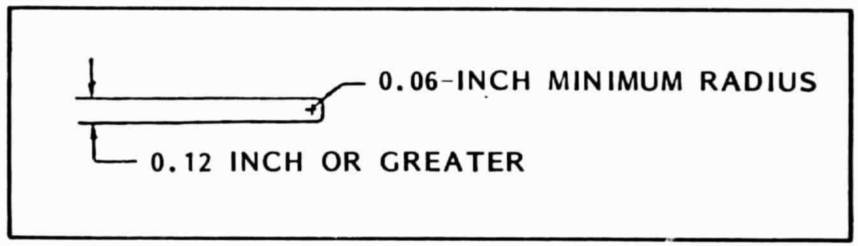
1.3.6.6 Lighting of access openings, workstations, and translation areas should be as specified in Section 5.7.

1.4 Structure - Skin Surface

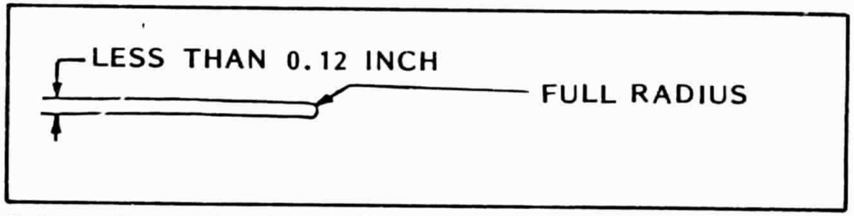
Design of the spacecraft structure to meet maximum radii requirements should encompass the following.

1.4.1 Protruding metal edges, flanges, latch controls, hinges, structural protrusions, and other small hardware operated by a pressurized gloved hand or which may come in contact with the suited astronaut should be compatible with the following minimum radii requirements.

1.4.1.1 Exposed edges with a thickness greater than or equal to 0.12 inch should be rounded to a minimum radius of 0.06 inch (Reference 21).

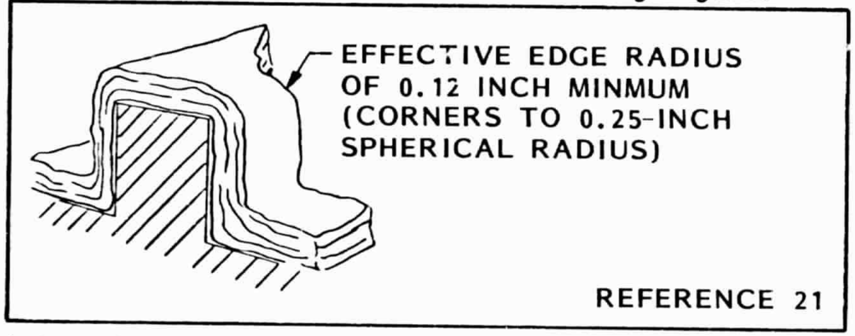


1.4.1.2 Exposed edges with a thickness from 0.06 inch to 0.12 inch should be rounded to a full radius (Reference 21).



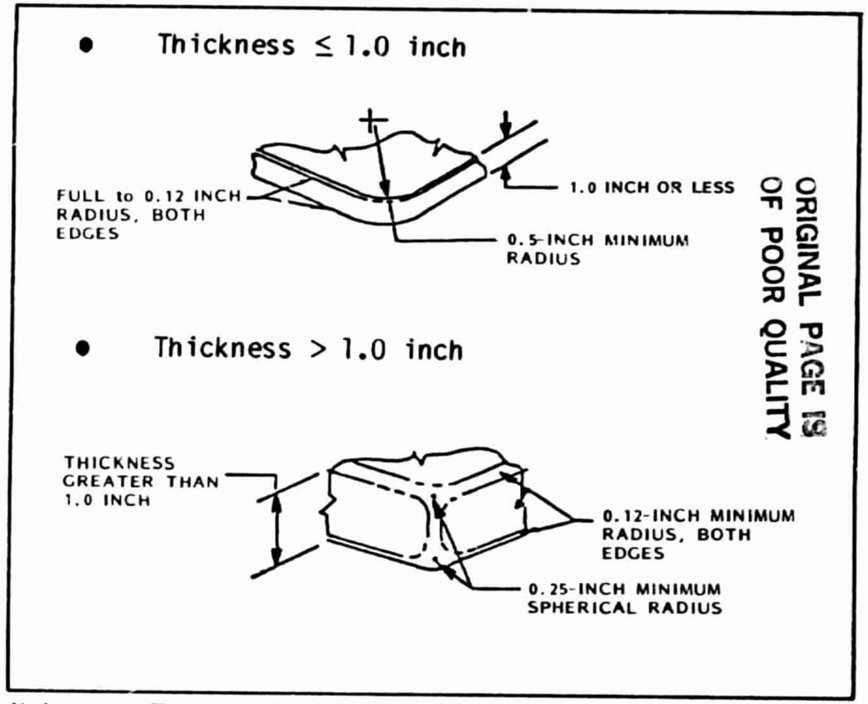
Note: Exposed edges with a thickness less than 0.06 inch should be treated to increase the edge thickness to a minimum of 0.06 inch. Multilayered insulation (MLI) should not be considered in meeting the minimum edge and protrusion requirements noted above.

1.4.1.3 Uses of MLI blankets to protect sharp edges or corners are described in the following figure.



Note: Where sharp edges or corners cannot be made safe through the use of MLI blankets or manufacturing methods, an approved means of protection (such as RTV or an approved substitute) should be applied to the area concerned.

1.4.1.4 Exposed corners should be rounded to a 0.5-inch minimum radius for material 1 inch or less thick, and rounded to a 0.25-inch spherical radius for thicknesses greater than 1.0 inch. Box edges should be rounded from 0.12 inch to full radius for material 1 inch or less thick, and 0.12 inch minimum for material over 1 inch thick, or covered with a material to ensure the equivalent effective radii (Reference 21).



Note: These dimensions will be required for all exposed corners and edges that may be accessible to a suited EV crewmember.

1.4.2 Burrs should be eliminated on surfaces, edges, and fasteners.

1.4.3 Avoid or guard uncovered holes or openings that allow EV gloved finger access to a depth of 0.75 inch or greater and that are round or slotted with a 0.75 inch to 1.50 inch width.

1.4.4 Lap joints and surface mismatch greater than 0.03 inch in sheet metal and adjacent surfaces should have edges designed in compliance with Section 1.4.1. In addition:

- All surfaces should be mated (in elevation) within 0.03 inch of the flat surface at mated edges.

- All exposed edges should be smooth and rounded to a minimum radius of 0.06 inch <u>or</u> chamfered to a 45° break of edges <u>or</u> covered with an appropriate material.

1.5 <u>Structure - Multilayered Insulation (MLI)</u>

The following guidelines for MLI design and utilization should be considered.

1.5.1 To prevent inadvertent snagging by crewmember's hands, feet, tether hooks and/or associated tethering equipment, vent hole diameters in the outer (exposed) layer of MLI should not exceed 0.4 inch.

1.5.2 MLI blanket designs should not be substituted for rounding of two-plane edges and three-plane corners. Where exceptions are granted and MLI covering is required, caution and warning labeling should be provided in accordance with Section 5.0 (Design for Crew Interface).

1.5.3 When visual and physical access to fasteners, displays, controls, alignment devices, and mechanisms are required, provisions such as "grasp areas" should be incorporated into the thermal design of MLI to prevent an astronaut's gloved hand from changing or altering the MLI thermal and surface characteristics.

1.5.4 Where appropriate, temporary holddown devices such as velcro, snaps, or clips should be provided to secure MLI "open" when access beneath it is required.

1.5.5 All edges, openings, and corners of MLI blankets should be arranged to minimize the potential for snagging, gathering, or separating. Edges and openings should be reinforced and secured to prevent inadvertent snagging of the EMU displays/controls and crew pressure garment assemblies by airborne support equipment (ASE), tools, personnel, equipment tethers, protuberances, and abrasive surfaces.

1.5.6 Visual and physical access to fasteners and alignment guides and minimum gloved-hand clearance envelopes should not be compromised by the arrangement of MLI blankets. Clearance for equipment changeout should be such that MLI does not have to be removed or pulled back for visual access or replacement.

1.5.7 Payload MLI applications exposed to crewmember activity should meet the crewmember-imposed inadvertent load criteria shown in Table 5.4-5.

1.6 <u>Mechanical</u>

The following guidelines are recommended methods and techniques for mounting, installing, and operating mechanical elements.

1.6.1 Whenever possible, backlash forces in mechanical devices should be eliminated for protection of crew and equipment.

1.6.1.1 When spring-back or backlash forces cannot be totally eliminated, then the maximum allowable force should be less than 0.25 pound.

1.6.1.2 All devices that have the potential for backlashing should meet the minimum edge radii requirements without the use of surface/epoxy applications.

1.6.2 Articulating mechanisms, levers, switches, and knobs should incorporate low-force applications (25

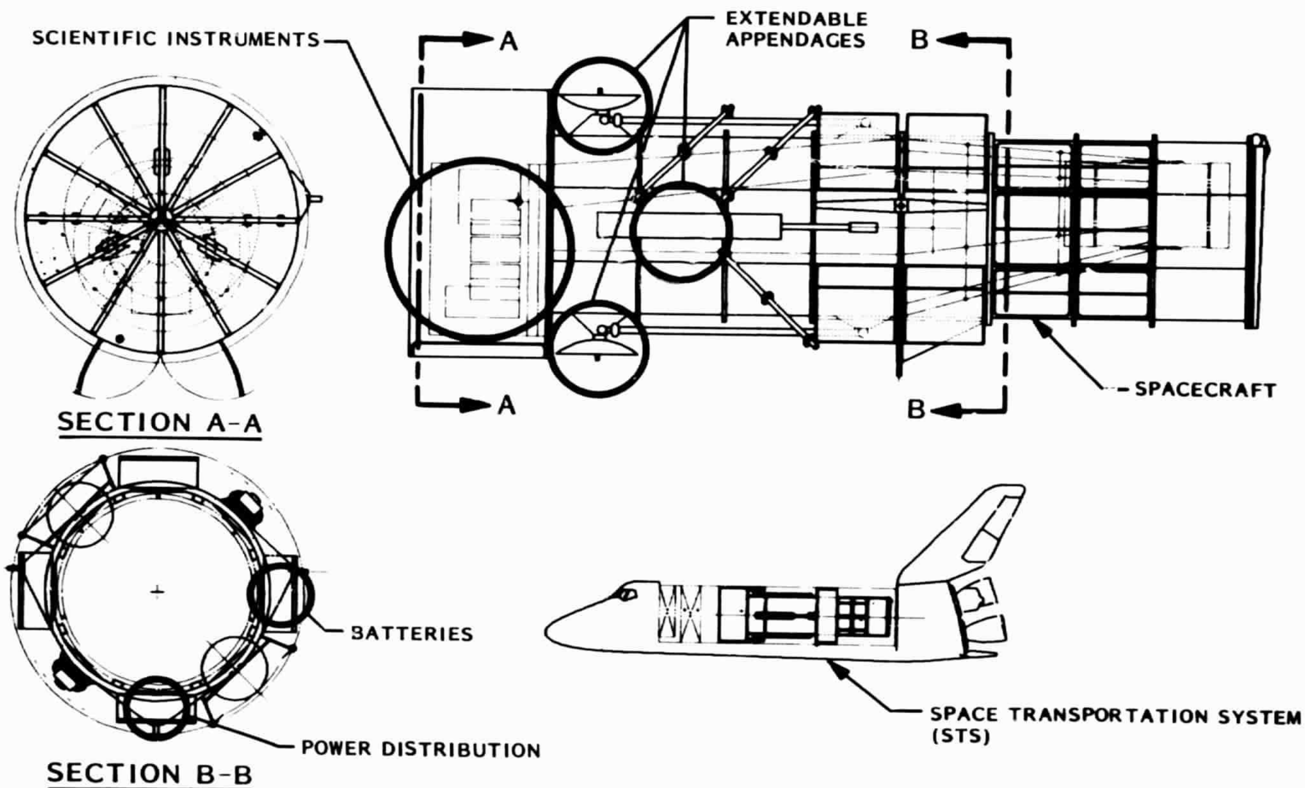
pounds) and provide positive steps/indents or visual feedback to verify operation and correct positioning.

1.6.3 When possible, labels and markings indicating the movement direction and degree of travel should be provided for the following:

- Mounting aids
- Connector interfaces
- Rails/guides.

SECTION 2.0

DESIGN OF ORBITAL REPLACEABLE UNITS



2.0 DESIGN OF ORBITAL REPLACEABLE UNITS

2.1 General

An orbital replaceable unit (ORU) is an equipment assembly configured to permit its removal or replacement on orbit either by a crewmember or by mechanical means. When incorporated into the design of a satellite, this feature extends its useful life and also allows for scientific and technical hardware upgrading. A typical spacecraft designed for orbital maintenance is shown in Fig. 2.1-1 with its numerous ORU placements. Packaging an ORU involves many design requirements that directly affect the following:

- Equipment package configuration
- Mounting interfaces
- Volumetric constraints
- Equipment attachment features
- Mechanical devices
- Tool interfaces
- Cable connector interfaces
- Grounding interfaces
- Surface finishes
- Mounted crew aids
- Maintenance accessibility
- Thermal interfaces.

2.2 Experiment Package Configuration

The following are suggested methods and techniques for layout and configuration of ORUs.

2.2.1 As an element of the ORU design, the equipment package designed as an orbit maintainable unit will be configured in various shapes and sizes. Some ORUs such as acquisition lights or sensor detectors are no larger than 2 or 3 cubic inches, while some scientific instruments can be as large as a phone booth.

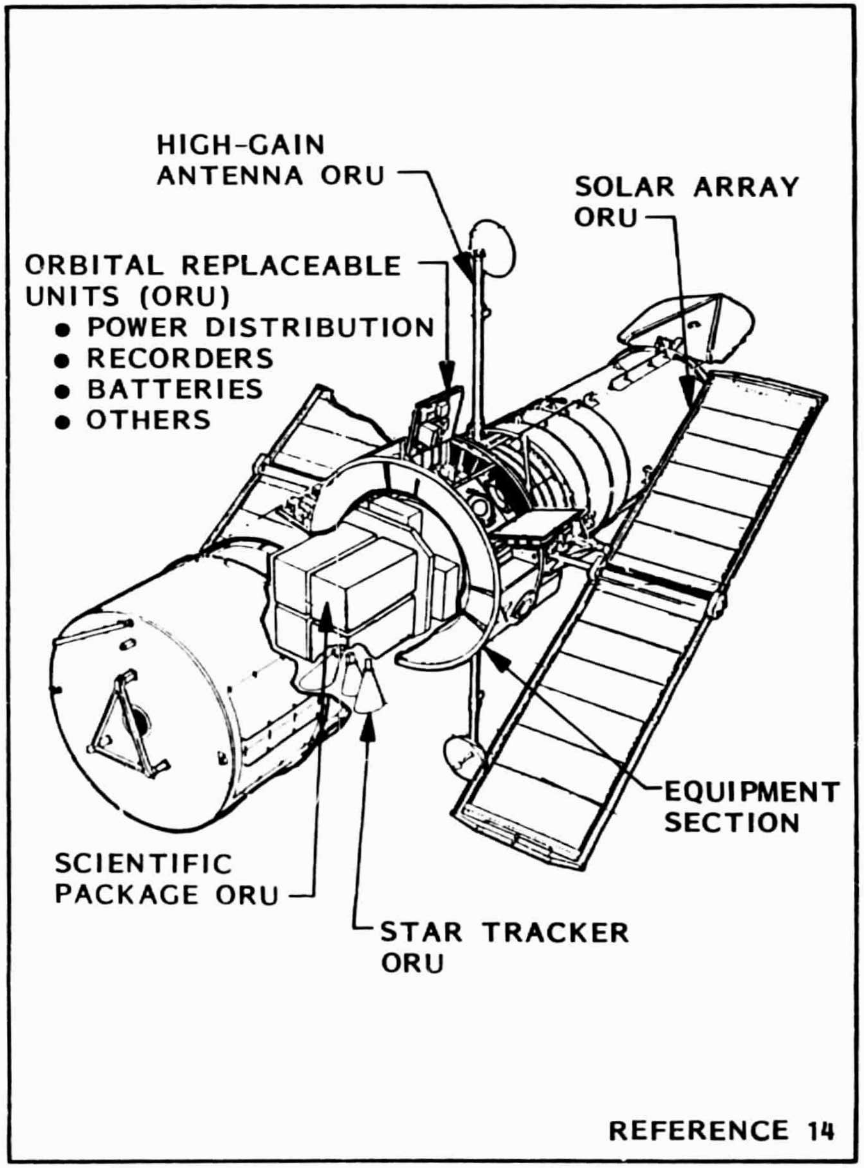


Fig. 2.1-1 Spacecraft Designed for Orbital Maintenance

2.2.2 The ORU solution for small packages such as lights or detectors usually involves adapting them to an intermediary tray or bracket to make them removable and manageable. All ORUs are keyed to program-typical interface control documents.

2.2.3 Most electronic packages should be designed in a rectilinear form. These are adapted for on orbit changeout by adding required mechanical features (electrical connectors, drives, fasteners) directly onto the package as in the electronics control unit example shown in Fig. 2.2-1.

2.2.4 Where qualified Government-furnished equipment (GFE) is involved that cannot be redesigned or modified, then that package should be environmentally buffered (e.g., tray-mounted) to avoid package reconfiguration (see Fig. 2.2-2).

2.3 Mounting Interfaces

Consider the following guidelines when designing ORU mounting interfaces.

2.3.1 The footprint of an ORU is the mounting surface or contact area. When designing this interface, the following points should be considered (see Fig. 2.3-1):

- Cone and path of removal/installation area
- Labeling or marking
- Visual identification
- Correct orientation
- Tool access.

2.3.2 The following alignment steps should be considered when designing the mounting interface of an ORU.

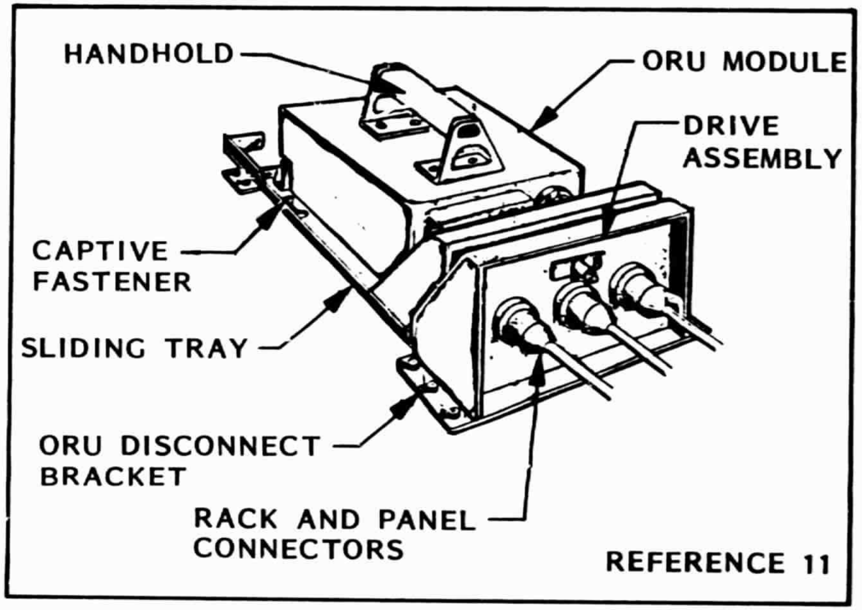


Fig. 2.2-1 Orbital Replacement Unit (ORU)

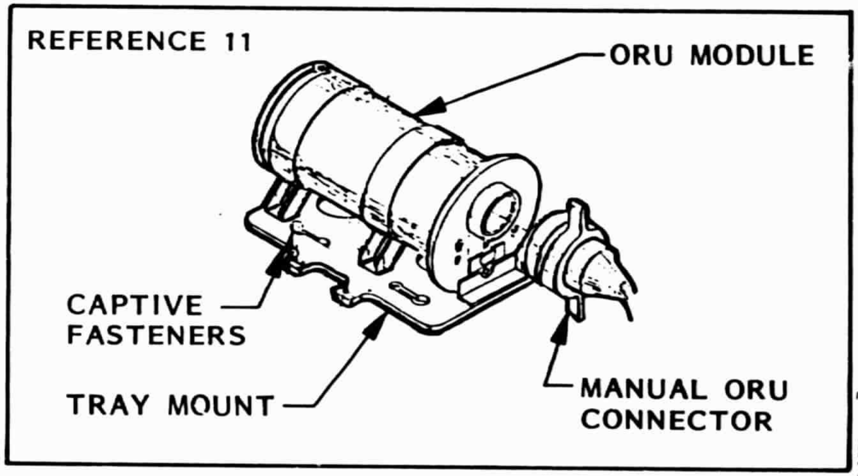


Fig. 2.2-2 A Tray Mount

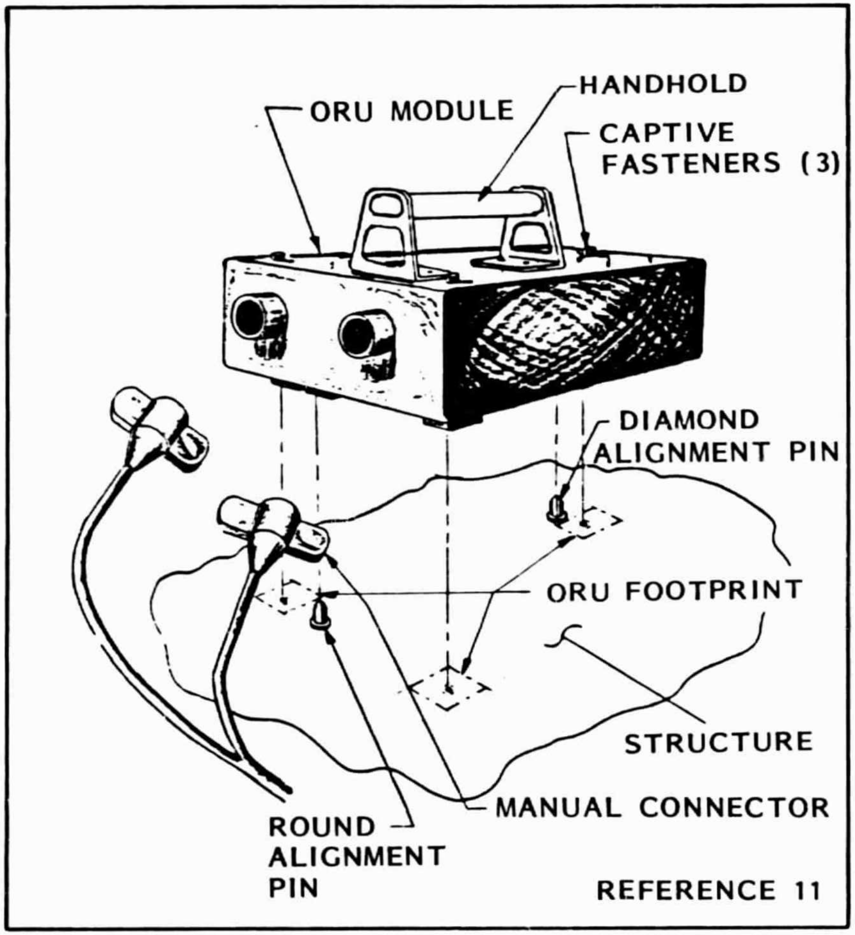


Fig. 2.3-1 Manual ORU Elements

2.3.2.1 The first step involves a coarse or gross alignment, such as obtaining correct orientation of two dimensions (i.e., placing a rectilinear ORU into a position for installation). This alignment process is usually visual and would normally be undertaken by the flight crew.

2.3.2.2 The second step in alignment requires that the ORU properly engage the alignment device.

2.3.2.3 The third step aligns the ORU to the appropriate final engagement tolerance for critical alignment, provides structure tie-down to carry the loads, and aligns rack and panel connectors.

2.3.2.4 Recommended alignment methods and techniques follow for various steps in the process:

2.3.2.4.1

- Indicate footprint outline of ORU on mounting surface
- Consider using the following coarse alignment techniques:
  - Center matching plates
  - Ramp guides
  - Cone standoff mounts
  - Corner guides.

2.3.2.4.2

- Consider using the following "next finer" alignment techniques (if required):
  - Edge notching
  - Tapered guide rails - outer ends equipped 30° to a depth of 0.375 inch
  - Tapered box sides and alignment pins

2.3.2.4.3

- Consider using the following final alignment techniques (if required):
  - Detent engagements
  - Tapered pin engagement
  - Final capture of pin/bolt in slot
  - Hook on clasp capture.

2.3.3 When alignment tolerances have not been specified elsewhere, Table 2.3-1 should be used as a guideline.

TABLE 2.3-1 ALIGNMENT TOLERANCES

TECHNIQUE	RANGE TOLERANCE (GENERAL)	COMMENTS
1. HOLE PATTERN		
A. FASTENERS (SCREW/BOLT), 2 OR MORE	–	
B. PINS IN HOLES	0.006 TO 0.0002	• IN BASE FLANGE OF SUBSTRATE
C. FASTENERS WITH ADJACENT PINS • ALONG ONE EDGE • ON OPPOSITE EDGES	0.013 TO 0.0003	• PIN TANGENT TO PART ALIGNMENT EDGE
2. GUIDES		
A. CORNER BRACKETS • COARSE USING PINS FOR FINAL ALGNMT • FINITE WITH INTEGRAL PINS	0.1 TO 0.06	• COARSE ALIGNMENT ONLY
B. INCLINATION (DRAFT)		• PROVIDES ANGULAR HOMING ONLY
3. EXPANDING BOLTS – FILLS HOLE	0.0005 TO 0.0002	• CONCENTRICITY TOLERANCE QUESTION
4. THREADED PART A. TURNBUCKLE B. THREADED SCREW	0.05 TO 0.01	• REQUIRES SUPPLEMENTAL MEASUREMENT
5. SLIP A. SLOT/KEY	0.04 TO 0.02	• COARSE ALIGNMENT – VERTICAL ROLL • ACCEPTABLE FOR FLATS MOUNTED ON SUBSTRATE

2.4 Volume Constraints

The following guidelines should be considered when designing for crew accessibility.

2.4.1 Removal/Installation. When configuring an ORU for removal or installation:

2.4.1.1 Clearance between staggered rows of bare connectors should be at least 2.5 inches (see Fig. 2.4-1).

2.4.1.2 Clearance between single rows of bare connectors should be at least 1.6 inches.

2.4.1.3 Clearance between staggered and single rows of winged connectors should be at least 1.5 inch (see Fig. 2.4-2).

2.4.1.4 Winged handle grips on connectors requiring gloved-hand access should be at least 1.0 inch long.

2.4.1.5 Tool engagement/disengagement and operating swept volume should be incorporated for connector block mate/demate of tray-mounted components (see Fig. 2.4-3).

2.4.1.6 Where gloved-hand clearance is required adjacent to ORUs, the following dimensions are highly

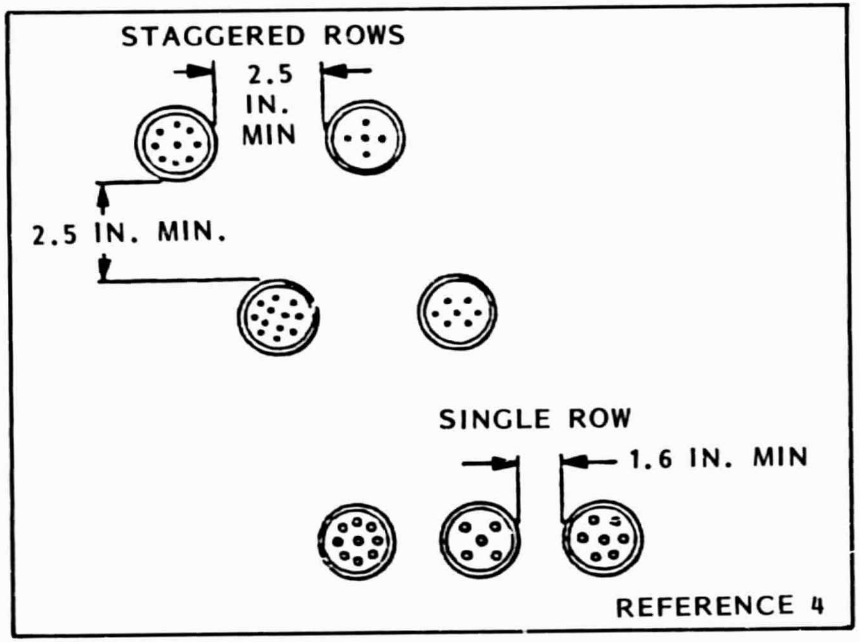


Fig. 2.4-1 Minimum Clearances Between Single Rows and Staggered Rows of Connectors

desirable:

- Clearance between ORUs, ORU/structure, ORU/cable, etc., should be at least 8 inches high, no more than 19 inches deep, and at least 10.5 inches wide (see Fig. 2.4-4).

2.4.1.7 ORUs should be removed or replaced along a straight or slightly curved line.

2.4.1.8 Provisions should be made to restrain demated connectors or grounding straps away from the ORU removal/installation path.

2.4.1.9 ORU-to-ORU layout spacing should permit visual and tool access to the fastener.

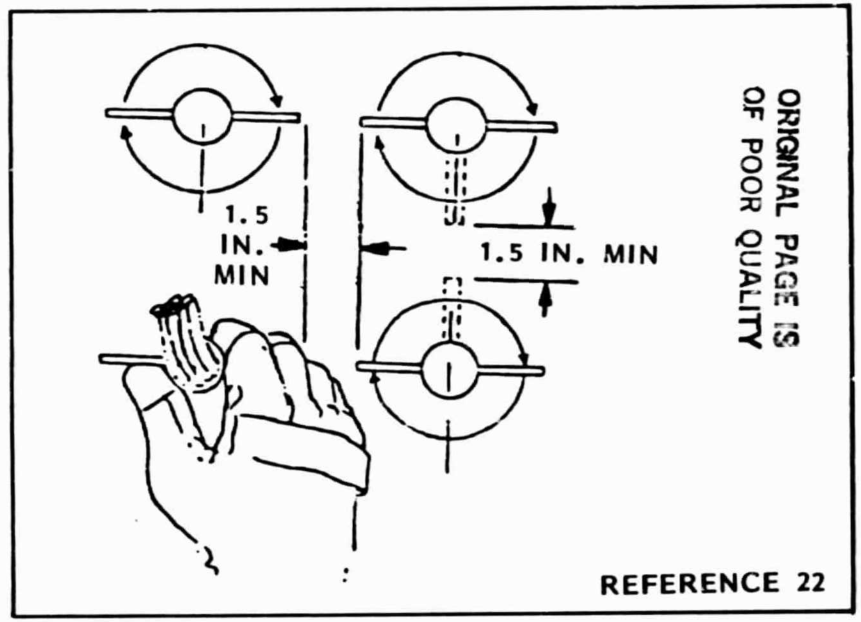


Fig. 2.4-2 Minimum Clearance required Between Connector Tabs for EV Gloved-Hand Access

2.4.1.10 ORU mounting techniques and location should minimize/eliminate collateral damage potential during ground/orbit changeout activity (see Fig. 2.4-5).

2.4.1.11 Maximum size of any ORU (excluding scientific instruments) should be 40 by 30 by 20 inches.

2.4.1.12 ORU installation fasteners should be captive. In addition:

- Fastener heads should be 7/16-inch "hex" (where practical).
- A standard ratchet wrench with extension and 7/16-inch socket should be used for fastener tightening/backout.

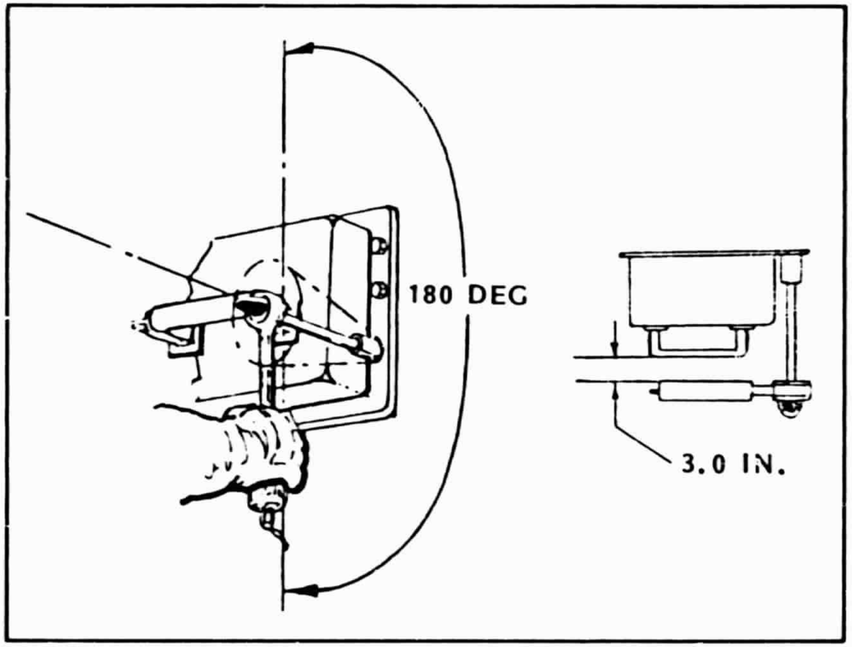


Fig. 2.4-3 Minimum Sweep Clearances Between Interface Tools and Hardware/ Structures

- The number of ORU fasteners used should be kept to a minimum.

2.4.1.13 ORU mounting techniques and fasteners should also be used for mounting spares and EV work platforms. In addition:

- ORUs should be mountable in any direction to take launch loads.
- ORUs should accommodate Orbiter cargo bay environments, where practical.

2.4.1.14 ORUs should be sized to allow their passage through an access door with a minimum clearance of 4 inches at any point.

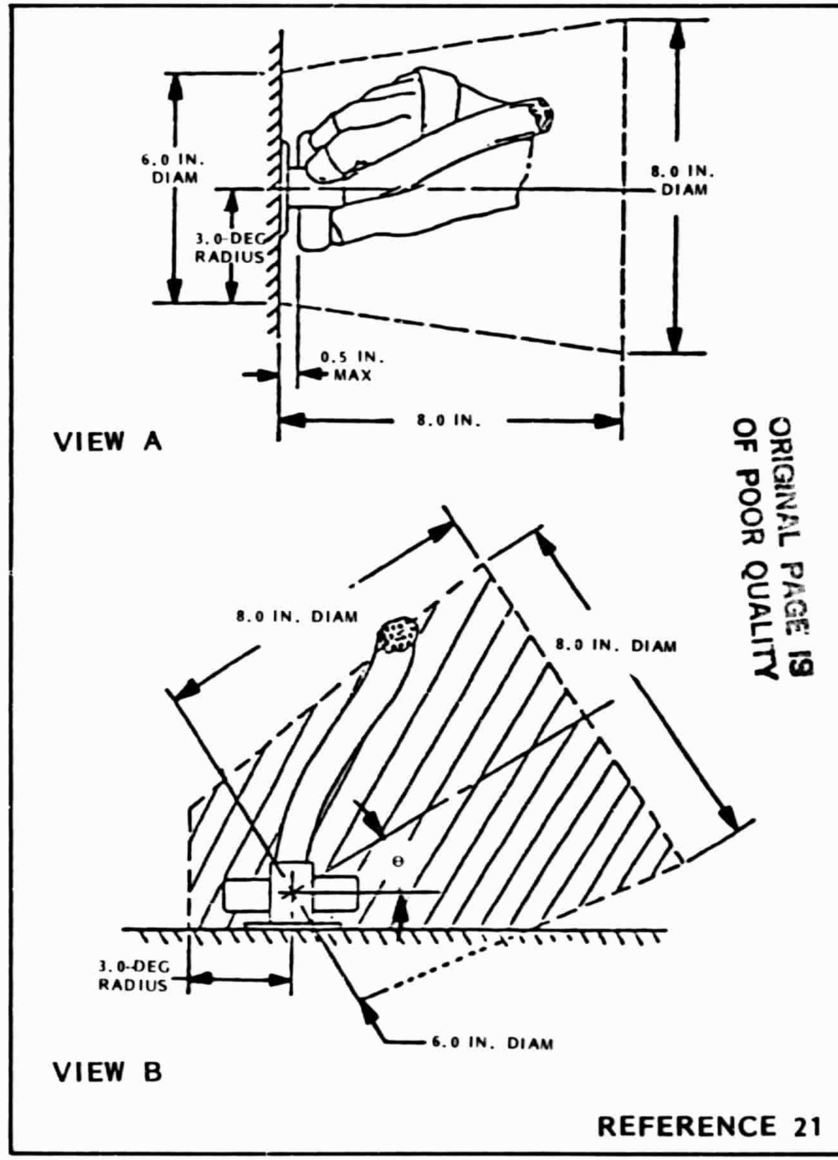


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Fig. 2.4-4 EV Gloved-Hand Clearance Envelope for Wing Tab Connector or Equipment Tether Operation

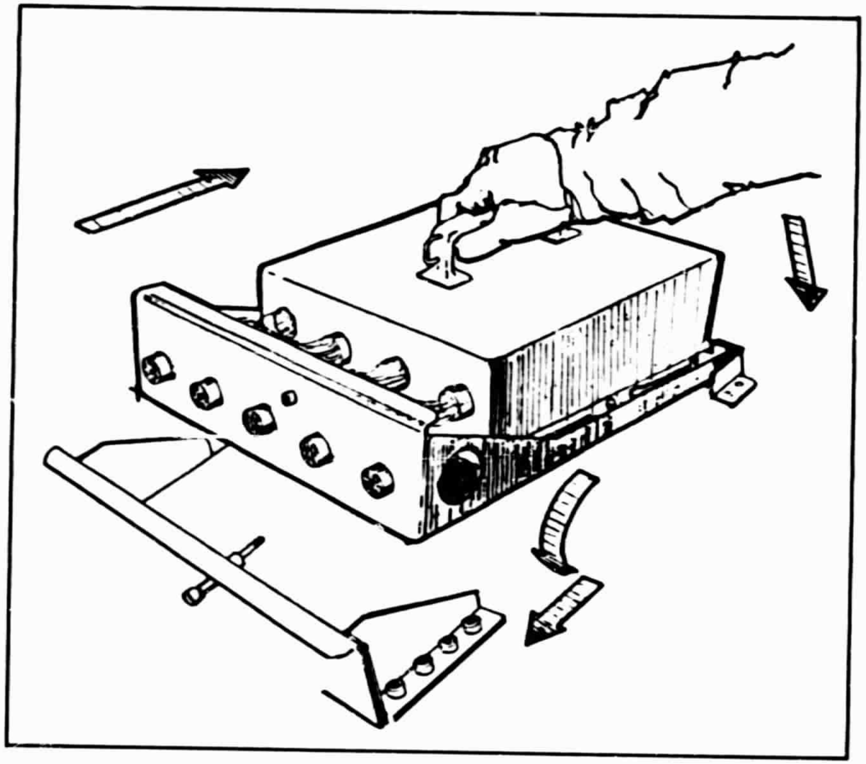


Fig. 2.4-5 ORU Mounting Technique Utilizing Alignment Guides and Rack/Panel Design

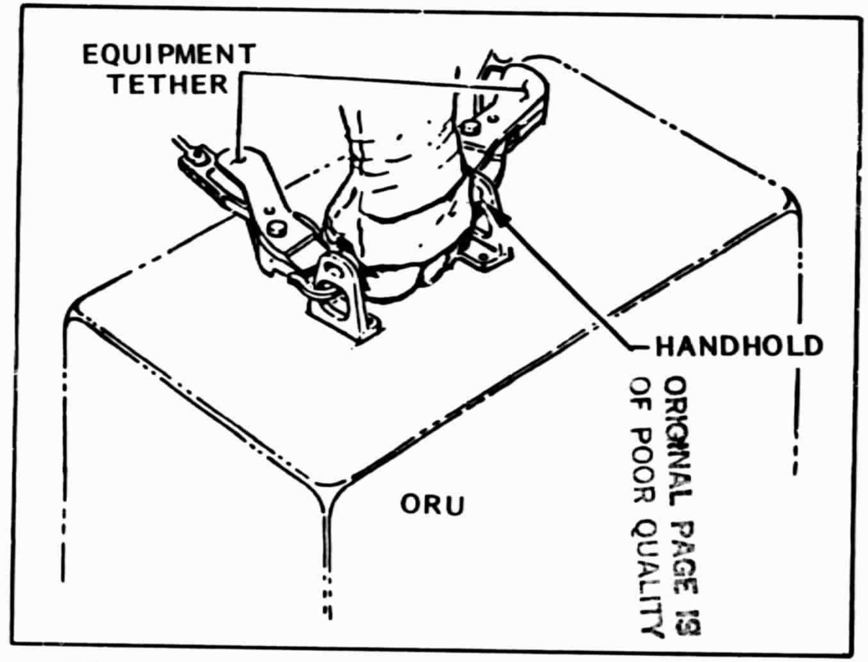


Fig. 2.4-6 ORU Design with Center of Gravity Located Handhold and Provisions for Equipment Tethering

2.4.2 Handling. Consider the following guidelines when designing the handling interface of an ORU.

2.4.2.1 ORUs should incorporate provisions for a handle located as close to the center of gravity of the ORU as practical.

2.4.2.2 Each ORU should be provided with a minimum of one tether ring (see Fig. 2.4-6). In addition:

- The ring should be totally accessible.
- The ring shape should preferably be a "D."

2.4.2.3 Permanently installed ORU handles should be given preference over portable handholds (see Fig. 2.4-7). In addition:

- Minimum clearance between lower surface of the handhold and the mounting surface should be 3.0 inches.
- Minimum inside handhold grip length should be 6.0 inches.
- Handhold cross sections should be designed as shown in Fig. 2.4-7.

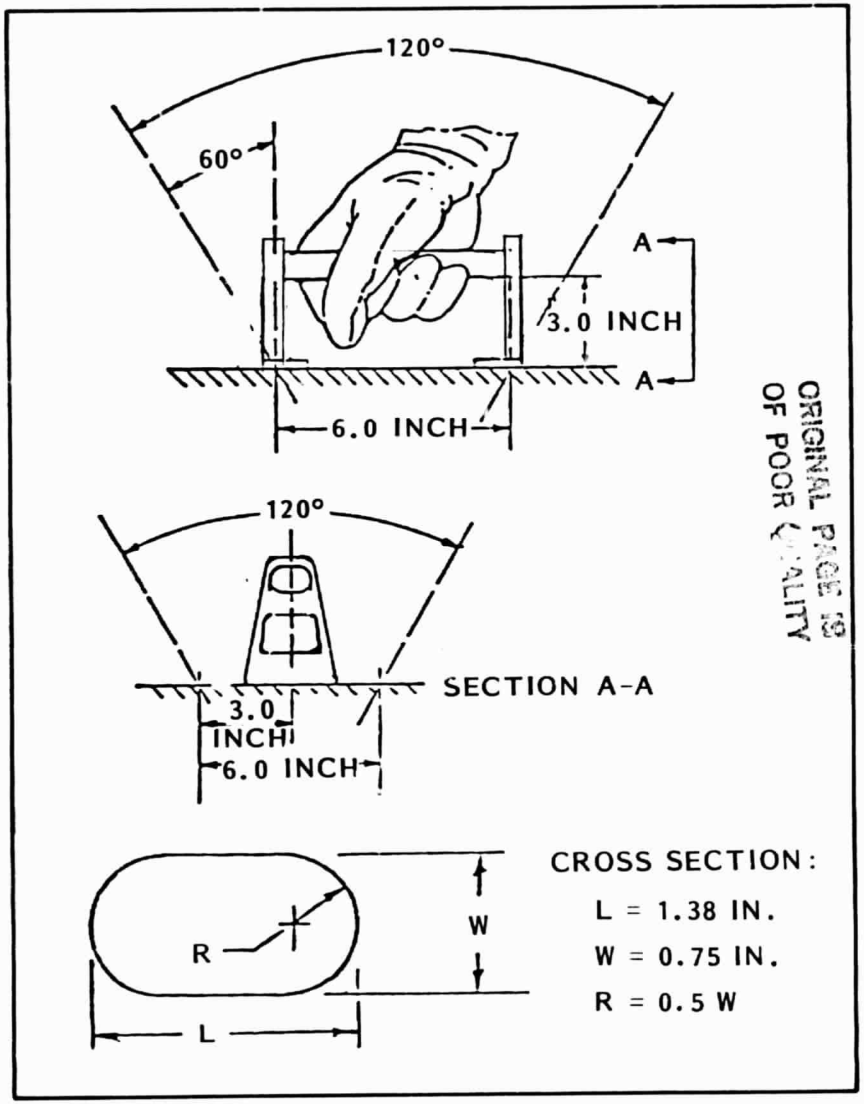


Fig. 2.4-7 EV Gloved-Hand Clearance Envelope for ORU Handle and Handrail Terminations

- Handholds should be designed to a minimum ultimate load of 280 ft-lb in any direction.
- Grip surfaces should be free of abrasive materials that could tear crewmember's glove.

2.5 Equipment Attachment Fasteners

Consider the following guidelines when designing attachment devices.

2.5.1 The preferred type of holddown/attachment device should be a captive fastener. The keyhole slot, U-slot, hook and lock, and off-center locks a-e also acceptable fastener devices (see Figs. 2.5-1 and 2.5-2).

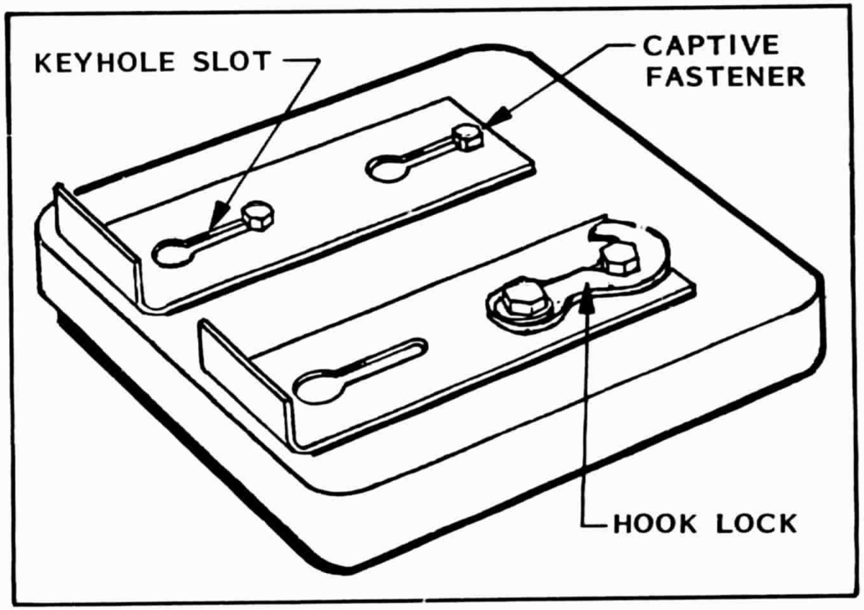


Fig. 2.5-1 Handhold Attachment Devices

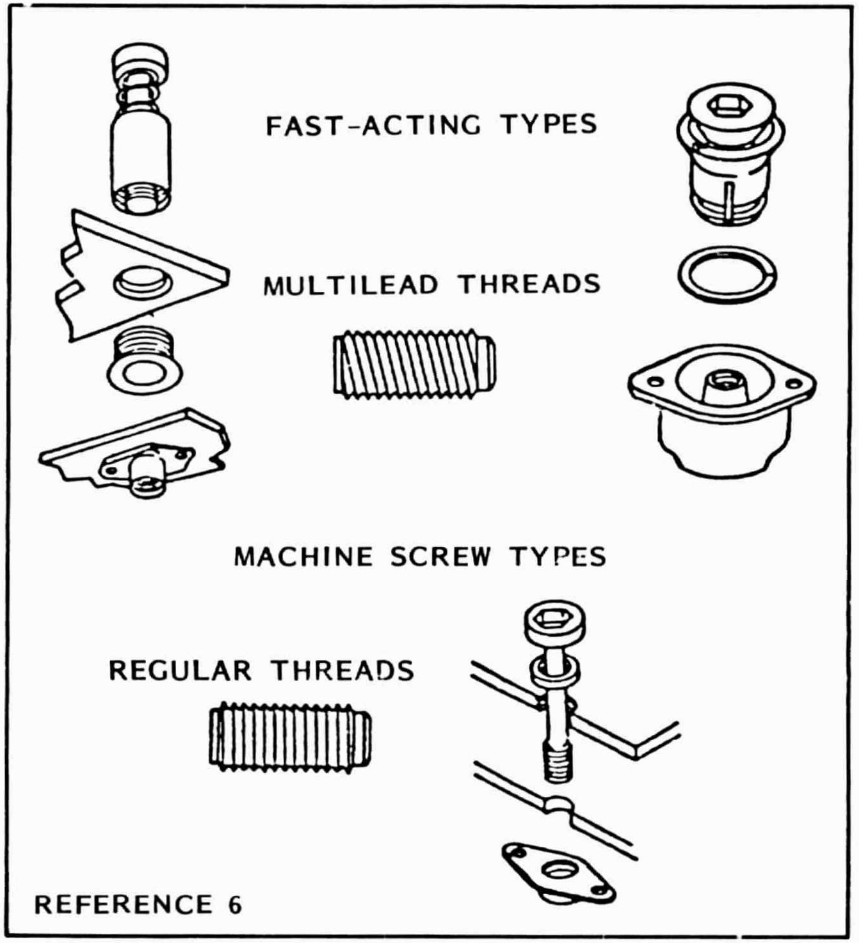


Fig. 2.5-2 Equipment Hold-Down and Attachment Devices

2.5.2 Preferred fastener characteristics are described below.

2.5.2.1 Fastener heads should be a 7/16-inch "hex" configuration (where possible) and should allow for a greatly enhanced grip area by the ratchet wrench.

2.5.2.2 Where positive and critical tool alignment engagement is required, the fastener head should incorporate an "allen head" design.

2.5.2.3 Countersink fasteners should be used where high shear loads will be encountered (approximately 150 pounds or greater) or where smooth surfaces are required.

2.5.2.4 If an ORU is installed on honeycomb or similar surfaces, an insert should be used to preclude the possibility of fracture cracks.

2.5.2.5 Fasteners on the ORU should be located to permit tool and EV gloved-hand access (see Section 3.0).

2.5.2.6 Maximum and recommended forces exerted by crewmembers on fasteners are shown in Section 3.0.

2.5.2.7 Quick-release fasteners should be used where very simplified engagement is needed and low load conditions exist (under 40 pounds). They generally are not used but, if required, the following criteria should apply:

- Rotary - A rotary handle mechanism should be used where jacking of rack and panel connectors is required to produce high insertion/removal forces.
- Lever handle - A lever handle type mechanism should be used where a medium-sized thermal contact area is required and electrical connections are other than rack and panel type.
- Latch and catch - These devices should be used only on low structural loading or jacking forces. They are fast and easy, require no tools, and have poor thermal path, but are good for securing panels, covers, and cases.

2.6 Mechanical Drives

Consider the following guidelines when designing mechanical drives for ORUs.

2.6.1 Among preferred types of mechanical drives are the following:

- Linkage
- Over center
- Screw drive.

2.6.2 ORUs with two electrical connectors or less do not require a mechanical drive for separation.

2.7 Tools/Usage

The following guidelines should apply when designing for tool accessibility and tool/hardware engagement.

2.7.1 Common tool and socket hex size should be used for all access door fasteners, mechanical drives, clamps, bolts, and other tool or ratcheting operations.

2.7.2 The recommended tool socket/screw head engagement is 0.3 inch.

2.7.3 A minimum of 1.0-inch-diameter socket clearance should be provided around all fastener and drive hex heads.

2.7.4 Tool use should not exceed a breakaway force of 20 pounds or a torque of more than 15 foot-pounds.

2.7.5 Most tool installations and operations should be designed for one-handed manipulation to allow using the other hand for restraint or position management.

2.7.6 The use of power tools should be considered for repetitive manual tasks.

2.7.7 The maximum usable depth between boxes and surrounding structures for manual EV crew operations should be 14 inches.

2.8 Cable/Connector

Consider the following guidelines for designing changeout of cables and connectors.

2.8.1 Cable/connector mate/demate mechanisms should provide positive detent/feel stops and/or visual feedback to prevent inadvertent operation.

2.8.2 Whenever possible, EVA connectors similar to those depicted in Fig. 5.4-1 should be used.

2.8.3 No unique tools should be required for connector mate/demate.

2.8.4 Connectors should be coded to aid recognition and eliminate incorrect mating. Techniques to be considered include:

- Keying
- Sizing
- Marking
- Labeling
- Location
- Cable length.

2.8.5 Connectors should include alignment provisions to facilitate initial engagement.

2.8.6 Connector and cable runs should be secured by a clamp and/or tie-wrapped every 18 inches.

2.8.7 Cables and cable runs should be located, routed, and protected to avoid damage by access doors, installation techniques, ground/orbit crew access, or damage from being bent and twisted sharply or repeatedly.

2.8.8 Demated connectors should be restrained away from the ORU removal/installation path.

2.8.9 Three or more electrical connectors per ORU should be mounted by rack and panel or ganged concepts and mated/demated by mechanical drive.

2.8.10 Individual connectors should be "scoop-proof" LJT Bendix or equivalent to MIL-C-38999, modified with tab rings (wing tabs). Both connector halves (plug/receptacle) should be from the same vendor.

2.8.11 Individual cylindrical bayonet electrical connectors for EV gloved-hand engagement should be used for a maximum of two connectors per ORU.

2.9 Grounding Considerations

The electrical and grounding guidelines of Section 7.5 should be considered when designing an ORV for changeout.

2.10 Surface Finish

Adhere to the guidelines of Section 1.4 whenever possible to prevent inadvertent damage to crew/equipment.

2.11 Mounted Crew Aids

Consider the guidelines provided in Section 5.5 when designing interfaces for crew aids.

2.12 Repair Accessibility

The following should be considered when designing an ORU for repair accessibility:

- Tool interfaces
- Visual access to labels and legends
- ORU remove/replace swept volume
- Tool remove/replace swept volume
- Connector handling swept volume
- Grounding strap handling swept volume
- Crew aid access
- Mechanical tie-down access
- Connector and grounding strap temperature tie-down
- Any required thermal protective surface access.

2.13 Thermal Interfaces

The following should be considered when designing thermal interfaces.

2.13.1 Rear surface support should be provided for thermal surfaces that may be contacted frequently by the EVA flight crew.

2.13.2 More durable thermal material (e.g., MLI) should be considered in areas where EVA crew impact (suit, tools, ASE) may occur.

2.13.3 Thermal materials should be removable where access to underlying ORUs may be required.

2.13.4 Suggested mounting techniques for removable thermal materials can include the following:

- Velcro hook and pile
- Snap "buttoning"
- Hinged panel.

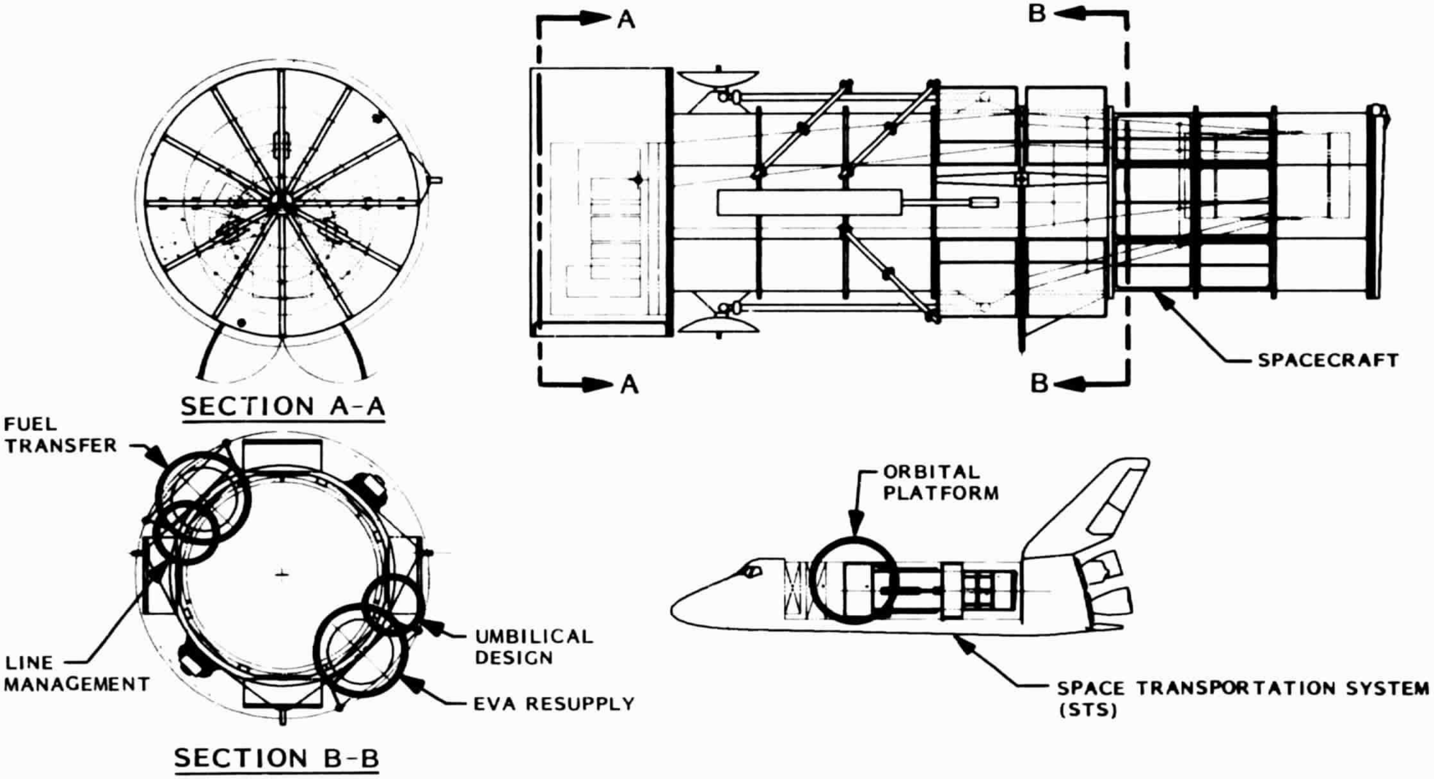
2.13.5 Active thermal control should be deactivated during ORU changeout.

2.13.6 Thermal surfaces should be designed to preclude temperatures that exceed the EV gloved-hand range of 275°F to -180°F for 0.5 minute at a grasping pressure of 1.0 psi.

2.13.7 Relief valves/vents should be provided on heat pipes where active coolant and associated pressure is encountered.

SECTION 3.0

EXPENDABLE RESUPPLY



3.0 EXPENDABLE RESUPPLY

3.1 General

This section presents design guidelines applicable to the resupply of liquids and gases on orbit. Table 3.1-1 gives a list of candidate resupply items. Two primary methods of resupply may be used for replenishment of expendables. Each method is briefly described below.

3.1.1 Remote Resupply. This method utilizes remote techniques with man-in-the-loop for control and operations override. Worksites can be located within the Orbiter cargo bay, some distance from the Orbiter, on a space station or at even higher altitudes and inclinations, such as GEO/HEO satellite locations.

3.1.2 EVA Resupply. This method utilizes a fully suited EV crewmember as the primary method for setup, connection, operation, monitoring, closeout, and system management of resupply. Typically, an IV crewperson located internal to the Orbiter, space station, or at a pressurized worksite would operate a resupply command and monitor panel in support of these activities.

For remote resupply, EVA can be used at various orbital locations, assuming allowances for safety, particularly relative to environmental hazards (i.e., radiation, solar flares, electrical charge buildup).

3.2 Guidelines

The following compilation of functional and design guidelines should be considered in the development of resupply systems. These guidelines are principally directed toward EVA and IVA considerations. However, many of the factors described also apply to remotely serviced resupply systems.

TABLE 3.1-1 TYPICAL EXPENDABLE CANDIDATES

Propellants:
• Nitrogen (N_2)
• Hydrazine (N_2H_4)
• Nitrogen Tetroxide (N_2O_4)
• Monomethyl Hydrazine ($N_2H_3CH_3$)
• Liquid Oxygen (LO_2)
• Liquid Hydrogen (LH_2)
Pressurants:
• Nitrogen (N_2)
• Helium (H_e)
Coolants:
• Liquid Nitrogen (LN_2)
• Liquid Helium (LH_e)
Lubricants:
• TBD

3.2.1 Monitoring. Table 3.2-1 presents a list of typical crew IV monitoring candidates for a representative fuel transfer system. Obviously, monitoring functions could be changed for resupply of other expendables, such as coolants. Those monitoring functions may also necessitate the simultaneous operation of controls to aid in the resupply servicing sequence. Thus, an integrated command and monitor crew work panel or station should be considered.

Should a remote servicing vehicle such as an orbital maneuvering vehicle (OMV) or orbital transfer vehicle (OTV) be used for resupply, a substantially enhanced command and monitor workstation would need to be designed and developed. This station would require control and monitoring of several major elements:

- Remote control of the OMV or OTV

TABLE 3.2-1 CANDIDATE MONITORING FUNCTIONS FOR RESUPPLY FUEL TRANSFER EXAMPLE

A. PROPELLANT TRANSFER SYSTEM (PTS) MONITOR

- QUANTITY OF FUEL BEING TRANSFERRED TO SPACECRAFT
- QUANTITY OF FUEL WITHIN SPACECRAFT TANKS
- PRESSURE/TEMPERATURE OF SPACECRAFT TANKS
- QUANTITY OF FUEL WITHIN PTS TANKS
- PRESSURE/TEMPERATURE OF PTS TANKS
- PRESSURANT TANK (PTS) STATUS
- VALVE ON/OFF AND SEQUENCING
- UMBILICAL STATUS (FLUID/POWER/SIGNAL)
- SCHEMATIC FLOW
- REALTIME DATA PROCESSING AND DISPLAY
- SAFETY AND INTERLOCKS FOR CRITICAL PTS/SPACECRAFT ELEMENTS
- THERMAL CONTROL/CONDITIONING
- PRESSURE VENT CONTROL
- LEAKAGE DETECTION
- HAZARD POTENTIAL

B. DETECTION – CORRECTION

- (BITE)

- Monitor and control of proximity operations and docking/berthing functions
- Control of remote umbilical mate and demate functions
- Monitor and control of resupply processes
- Safety monitoring
- Satellite monitoring and control during the resupply process.

3.2.2 Positioning and Holding. Satellites serviced at an orbital platform (i.e., Orbiter, space station, propellant farm) will require an interface to some method for positioning and holding at the resupply worksite. (An example of such a worksite is depicted in Fig. 3.2-1.) Accordingly, airborne support equipment (ASE) or equivalent hardware will be required. Candidate items and general guidelines governing their design are presented in Section 6.0. Additional guidelines are presented in the following paragraphs.

3.2.2.1 General guidelines for the resupply system proximity to the orbital system element being serviced are as follows:

- Minimize transfer line length
- Reduce line length to minimize possible bends in the line
- Shorten line length to reduce line management problems for EVA crewmember
- Reduce line length to lessen collateral damage potential of lines contacting items
- Shorten line length to permit potential for resupply transfer system and docking and berthing system cradle sharing
- Reduce line length to minimize EVA crew time.

3.2.3 Umbilical Design Guidelines. Several types of umbilicals could be utilized in support of the resupply process, including the following:

• Power	• Fluid/gas
• Signal	• Lubricant
• Pyrotechnic	• Grounding

The following general guidelines should be considered in the selection of an umbilical:

- Incorporate remote mate/demate capability
- Provide full EVA override (mate/demate); (see Fig. 3.2-2)
- Provide visibility for connect for status monitoring

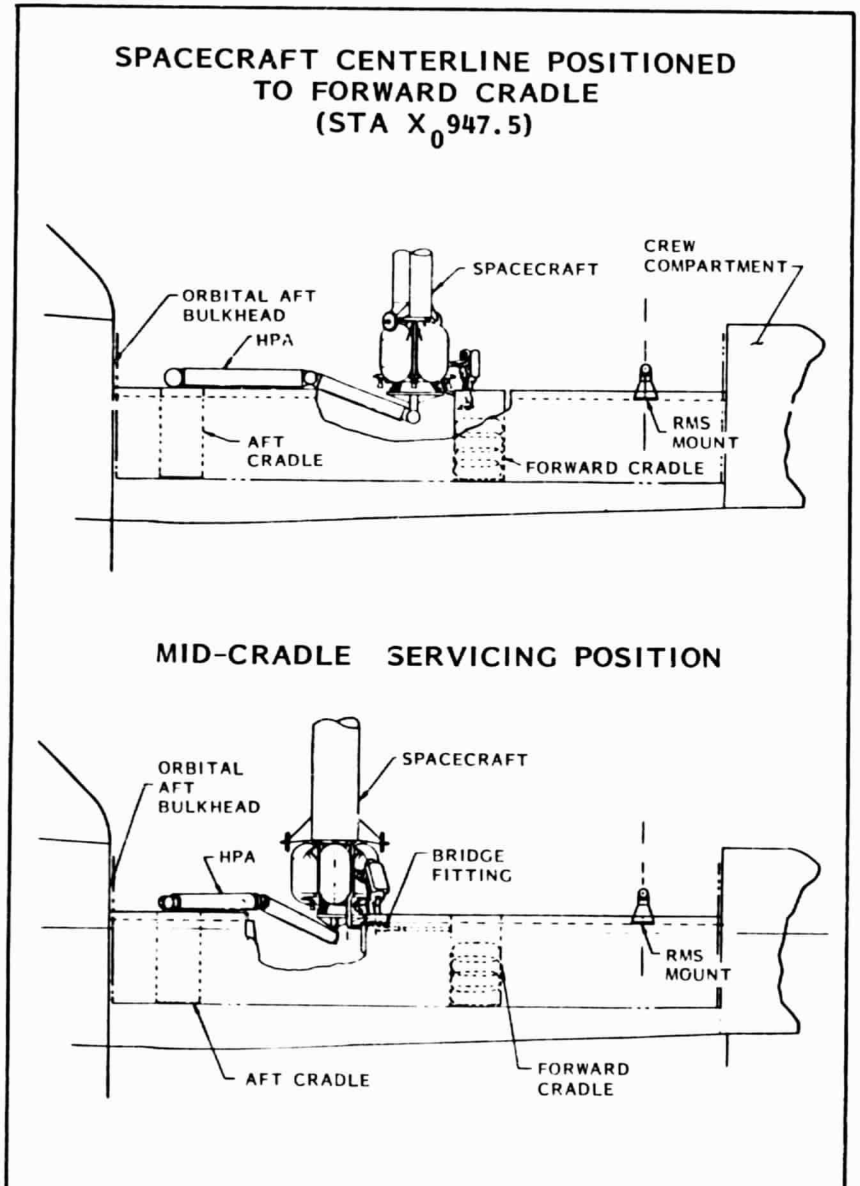


Fig. 3.2-1 Forward Cradle and Mid-Cradle Positioning at Resupply Worksite

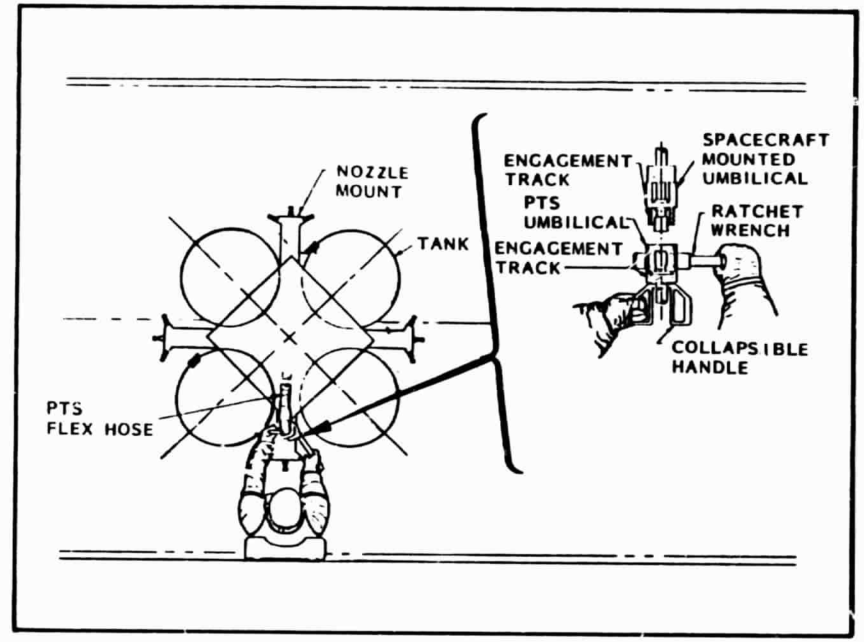


Fig. 3.2-2 Umbilical Engagement/Alignment and Mate/Demate Interface

- Incorporate a leak-free disconnect feature
- Include an autoindexing feature
- Ensure that mated loads are considered
- Provide a mechanical advantage for EVA umbilical mate/demate operations if forces exceed 40 ft-lb
- Design for a simple ratchet wrench interface for EVA override
- Do not incorporate stored energy sources within the umbilical if EVA crew interfaces are anticipated; if stored energy sources must be used, ensure that such sources can be deactivated by the EVA crew with no crew hazard
- Consider umbilical design as partially or fully integral to the docking and berthing subsystem

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- Umbilical location/arrangement within the resupply system should permit full crew reach, tool, and visual access (see Fig. 3.2-3)
- Mate/demate mechanisms should be designed to eliminate jamming or misalignment (see Fig. 3.2-4)

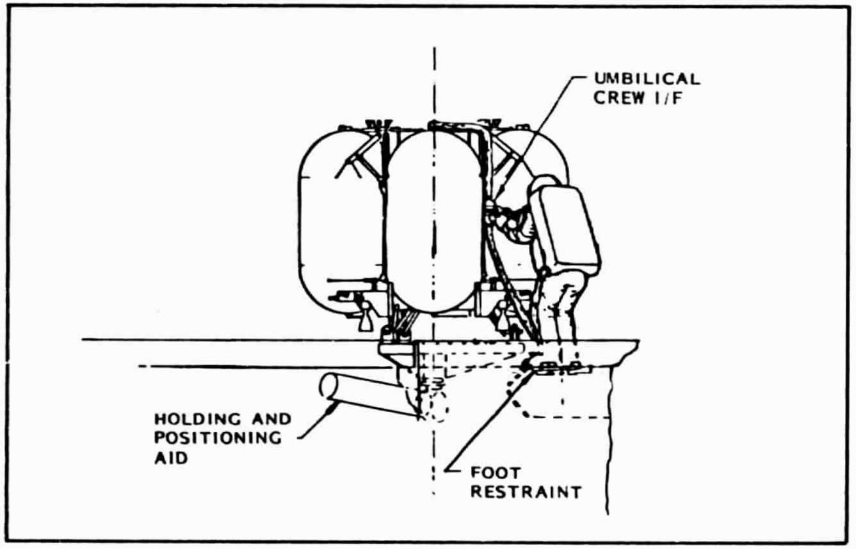

Fig. 3.2-3 EVA Umbilical Override

- Umbilical design, where possible, should incorporate sensor(s) to provide:
  - Expendable item leakage warnings
  - Integrity mate verification
- Required mate/demate mechanism stroke should be 3 inches or less
- Final maximum allowable offset should be ± 0.0675 inch
- Engage (mate) and disengage (demate) forces should be less than 260 ft-lb at approximately 300 psi
- Allowable angular misalignment should not exceed approximately $\pm 5°$
- Initial alignment should approximate the following:

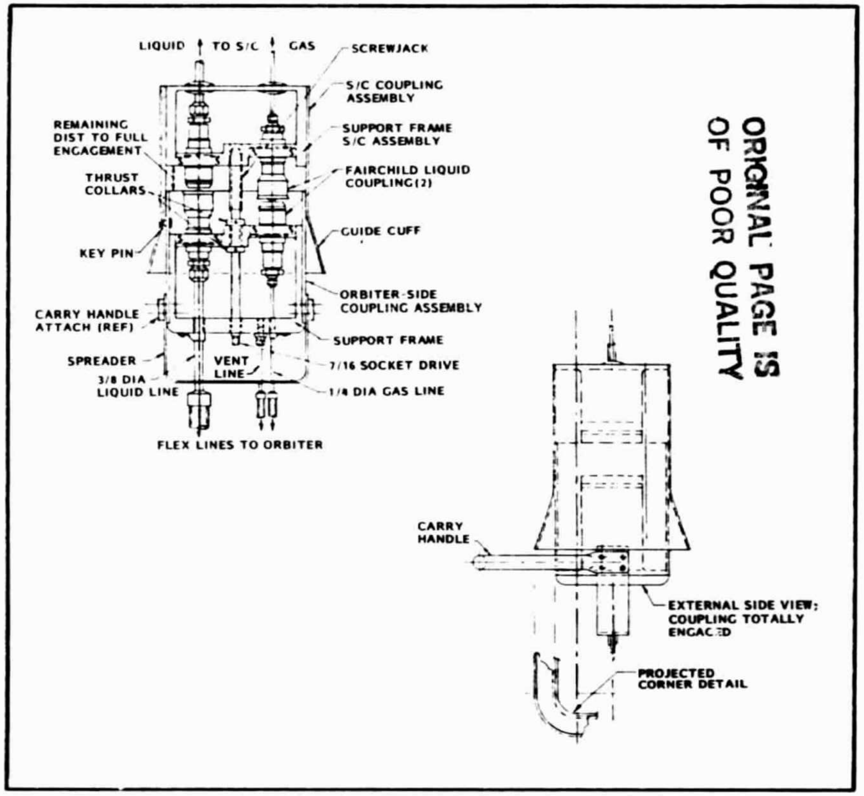

Fig. 3.2-4 Spacecraft/Orbiter Coupling System

  - Maximum offset, 0.75 inch
  - Maximum angular misalignment, $\pm 6°$ conical
- Leakage (if unavoidable for nonhazardous expendables) should not exceed the following:
  - Mated, 1×10^{-3} CC GH_e
  - Demated, 1×10^{-3} CC GH_e

- Demate breakaway with self-sealing should be considered integral to the design
- Umbilical engagement and alignment guides should be provided where required
- All umbilicals should be coded, where required, utilizing one or more of the

following techniques:

- Color
- Shape
- Location
- Size
- Line Characteristic
- Line Length

- Sharp corners and edges should be governed by guidelines similar to those delineated in Section 1.4. Safety factors beyond those described in this section are included in other sections of this document and should be applied, as appropriate.
- Umbilicals carrying hazardous expendables should incorporate appropriate caution flags, markers, or plates for both ground and flight crew recognition.

3.2.4 Umbilical Line Management. Provisions should be made in the expendable transfer system to enhance manual EVA crew management of the umbilical line during servicing. One approach to an umbilical line management is shown in Fig. 3.2-5. General guidelines governing these provisions are included in Section 3.2.2.1. Additional guidelines are as follows:

- A line/cable management technique should be considered to facilitate different servicing locations.
- The management technique should be compatible with anthropometric limits and strength capabilities of a fully suited EV crewmember.
- The management technique should consider both rigid and flex lines.
- Line tethering should be provided at all times during the transfer process.
- Management technique should incorporate the following features, as required:
  - Semiautomatic reel-up
  - Nonbending of line during reel-up
  - Tether attach methods
  - Standard safety provisions.

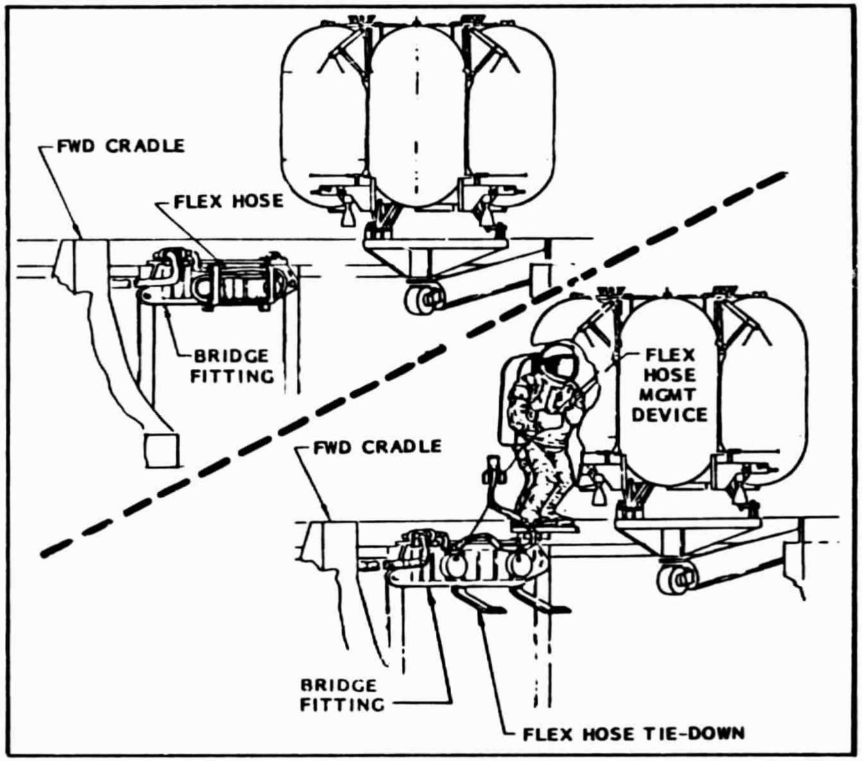

Fig. 3.2-5 Resupply Umbilical Management System in Orbiter Cargo Bay

- Line bends of less than 90° should be avoided.
- As a goal, the number of repeated bends should be kept to a minimum.

3.2.5 Remote Resupply. In addition to the general remote resupply guidelines included in Section 3.1 (General), the following guidelines should be considered:

- Remote operations should permit the crewmember to:
  - Monitor and command all events

- Override the resupply operation at any time during the sequence
- Abort the operation at the discretion of crewmember
- Vent expendables to reduce potential for an explosion
- Engage an automated leak detection sequence
- Establish the integrity of all orbital elements involved in resupply operations.

- Remote operations should be designed to permit the crew to dock/berth and attempt umbilical connect without expendables transfer until desired.
- Remote operations should include safing functions as integral to the servicing support task.
- Remote operations should permit the crewmember at the command and monitor station to determine the status of the satellite being serviced and, in particular, of the onboard system being resupplied. Orbiter aft flight deck remote operations worksite is shown in Fig. 3.2-6.

Note: This guideline is not intended to cover remote docking/berthing or proximity operations. These considerations, however, are pivotal to the success of resupply missions and should be included in the overall remote resupply operations study and development.

3.2.6 EVA Considerations. This section is directed toward those factors involved in EVA support of resupply operations, both in the Orbiter cargo bay and elsewhere.

3.2.6.1 Candidate EVA Functions. EVA functions in support of propellant transfer operations are shown in Tables 3.2-2 and 3.2-3. Manual EVA umbilical mate/demate would, if selected, include support of:

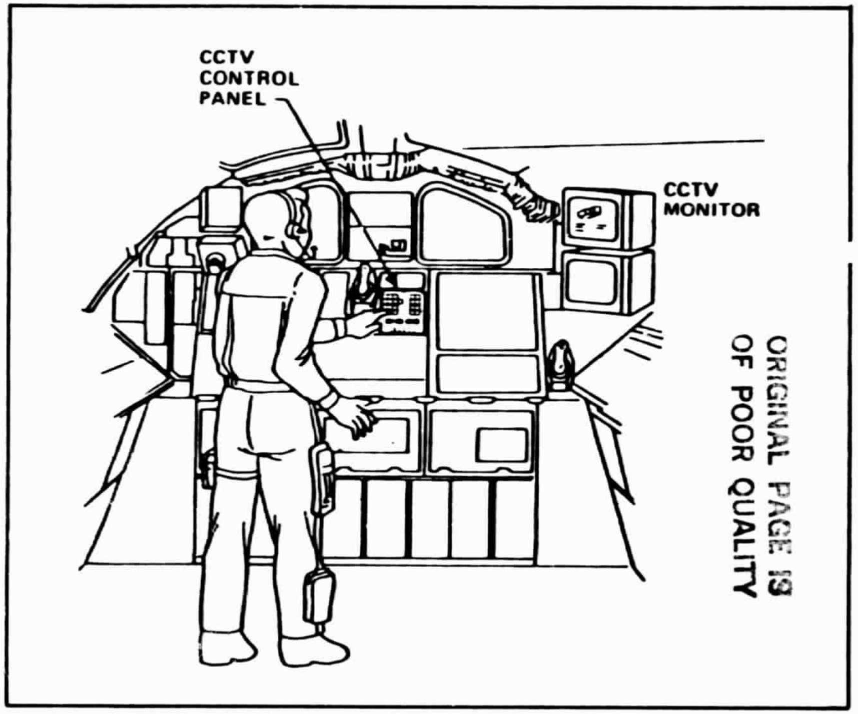

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Fig. 3.2-6 Remote Resupply Station in Orbiter Aft Deck Payload Station

- Initial satellite berthing and subsequent umbilical mate
- Nominal umbilical demate after expendable item transfer
- Contingency demate.

Use of the EVA crewmember should also be considered for any anomalous situations indicated in a Failure Modes and Effects Analysis (FMEA).

3.2.6.2 Crew Sizing Factors. Design of the resupply system should consider both male and female crewmembers and should include the following:

TABLE 3.2-2 TYPICAL EVA FUNCTIONS ASSOCIATED WITH PROPELLANT RESUPPLY

PRIMARY EVA FUNCTIONS

1. WORK STATION SET-UP/TEAR DOWN AND STOW/UNSTOW
2. PTS* AND SPACECRAFT INSPECTION – BASIC INTEGRITY
3. INSPECTION (DETAILED) FOR PROPELLANT LEAKAGE
4. HANDLING AND MANAGEMENT OF "FLEX" PROPELLANT HOSE LINES
5. ENGAGEMENT AND DISENGAGEMENT OF PTS SIDE UMBILICAL HALF WITH SPACECRAFT SIDE UMBILICAL HALF FIXTURES
6. MATE AND DEMATE OF UMBILICALS
7. MANUAL OVERRIDE OF PTS LOCATED CONTROLS (e.g. VALVES) IF REQD
8. MONITOR (IF REQD) OF CRITICAL PTS LOCATED DISPLAYS
9. LEAK ASSESSMENT IF APPROPRIATE
10. UTILIZATION OF LEAK KIT IF REQD
11. OTHER OVERRIDE OR UNSCHEDULED SUPPORT TASKS AS NECESSARY

*PROPELLANT TRANSFER SYSTEM

TABLE 3.2-3 TYPICAL EVA VISUAL MONITORING FUNCTIONS FUNCTIONS DURING PROPELLANT RESUPPLY

VISUAL CONFIRMATION OF UMBILICAL MATE

VISUAL CONFIRMATION OF FUEL TRANSFER LINE INTEGRITY

VISUAL CONFIRMATION OF VALVE/CONNECTOR INTEGRITY

VISUAL CONFIRMATION OF NO LEAKAGE

VISUAL CONFIRMATION OF PTS* "SHUTDOWN"

VISUAL CONFIRMATION OF UMBILICAL DEMATE – OPTION

* PROPELLANT TRANSFER SYSTEM

- Fifth percentile female to 95th percentile male crewmembers
- Associated anthropometric, reach, articulation, body, visual, and motion ranges
- Force application limits for both male and female crewmembers.

3.2.6.3 Crew EVA Aids and Tools. Several EVA crew aids and tools are expected to be required during resupply when the crew conducts servicing operations externally. Provided in Table 3.2-4 are examples of typical equipment and support items used for propellant resupply operations in the Orbiter cargo bay.

3.2.6.4 In designing resupply systems, consideration should be given to contingency operations support by EVA crewmembers. Potential EVA functions wherein design for override can be considered include, but are not limited to, the following:

- Override of umbilical(s)
- Emergency leak fix of non-crew-hazardous expendables
- Contamination clean-up of non-crew-hazardous expendables
- Valve override
- On-site pressure and temperature indicator observation
- Mechanical decoupling of items
- Override of a safed pyro item for mechanical disconnect.

3.2.7 Safety. The resupply system should be designed to ensure the safety of the crew and of other orbital elements (i.e., Orbiter, space station, propellant farm, OMV/OTV, other support platforms). Safety associated with the satellite being serviced should also be considered. Table 3.2-5 lists some potential hazards associated with expendable resupply systems and operations. Consideration should also be

TABLE 3.2-4 TYPICAL CREW AIDS AND TOOLS FOR SATELLITE SATELLITE PROPELLANT RESUPPLY IN ORBITER CARGO BAY

A. PTS AND/OR ORBITER *CARGO-BAY MOUNTED CREW AIDS
   1. STANDARD ITEMS
      - PORTABLE FOOT RESTRAINTS (PFR)
      - PFR RECEPTACLES
      - TETHER RINGS
      - HANDHOLD/RAIL
      - TRANSLATION RAIL (IF REQUIRED)
      - TETHERS (PERSONNEL/EQUIPMENT)
      - CONNECTOR-WING TAB
   2. MODIFIED ITEMS
      - RATCHET WRENCH WITH TORQUE LIMITER
      - RATCHET WRENCH SPECIAL END EFFECTOR (FOR VALVE OVERRIDE)

B. UNIQUE ITEMS
   1. LEAK DETECTOR
   2. SPILL KIT
   3. PROPELLANT/PRESSURANT FLEX HOSE LINE MANAGEMENT AND RESTRAINT DEVICES
   4. UMBILICAL PROTECTIVE END CAPS (CAPTIVE)
   5. BRIDGE FITTING "BOLT-ON" MOUNTING BRACKET

C. INTERNAL CABIN MOUNTED/LOCATED EQUIPMENT
   1. COMMAND AND MONITOR PANEL
   2. FLIGHT DATA FILE
   3. ALTERNATE STOWAGE AREA FOR CREW AIDS

D. ORBITER KIT ITEMS
   1. HELMET MOUNTED LIGHTS FOR EMU
   2. HELMET MOUNTED CCTV CAMERA

*CARGO-BAY MOUNTING IS OPTIONAL.

TABLE 3.2-5 CANDIDATE RESUPPLY SYSTEM HARDWARE/OPERATIONS HAZARDS

A. TANK EXPLOSION
B. LEAKAGE
C. CONTAMINANTS
D. OVER-PRESSURE
E. POWER SURGE
F. HYPERGOLIC REACTION
G. INCORRECT VALVE SEQUENCE
H. PURGING PROBLEM
I. GROUNDING
J. ADIABATIC COMPRESSION
K. OTHER

given to areas, mission segments, and systems where design for safety should be included (see Table 3.2-6).

3.2.7.1 Safety Documentation. Numerous safety documents and references may apply to the resupply systems and their design. Table 3.2-7 provides a partial list of such references.

TABLE 3.2-6 AREAS/SYSTEMS WHEREIN DESIGN FOR SAFETY SHOULD BE CONSIDERED

1. MISSION AND SYSTEM SAFETY
   - GROUND-PAD
   - LAUNCH/ORBIT/LANDING + ABORT
   - ROLL-OUT AND SAFING
2. CREW (IV AND EV) SAFETY
3. ORBITER INTEGRITY/SAFETY
4. SPACECRAFT DAMAGE
5. ASE DAMAGE
6. GROUND CREW (FACTORY TO PAD)

TABLE 3.2-7 CANDIDATE SAFETY DOCUMENTATION AND SELECTED REFERENCES

1. NHB 1700.7 (REV. A), SAFETY POLICY AND REQUIREMENTS
2. JSC 11123, STS PAYLOAD SAFETY GUIDELINES HANDBOOK
3. MIL-STD-1522, GENERAL REQUIREMENTS FOR SAFE DESIGN AND OPERATION OF PRESSURIZED MISSILE AND SPACE SYSTEMS
4. NSS/MP-1740.1, NASA AEROSPACE PRESSURE VESSEL SAFETY STANDARD
5. NHB 1700.1 (V1), NASA SAFETY MANUAL
6. SD-REG-127-4, SYSTEM SAFETY CERTIFICATION PROCEDURES AND TECHNICAL REQUIREMENTS FOR DoD STS PAYLOADS
7. MIL-STD-1574, SYSTEM SAFETY PROGRAM FOR SPACE AND MISSILE SYSTEMS

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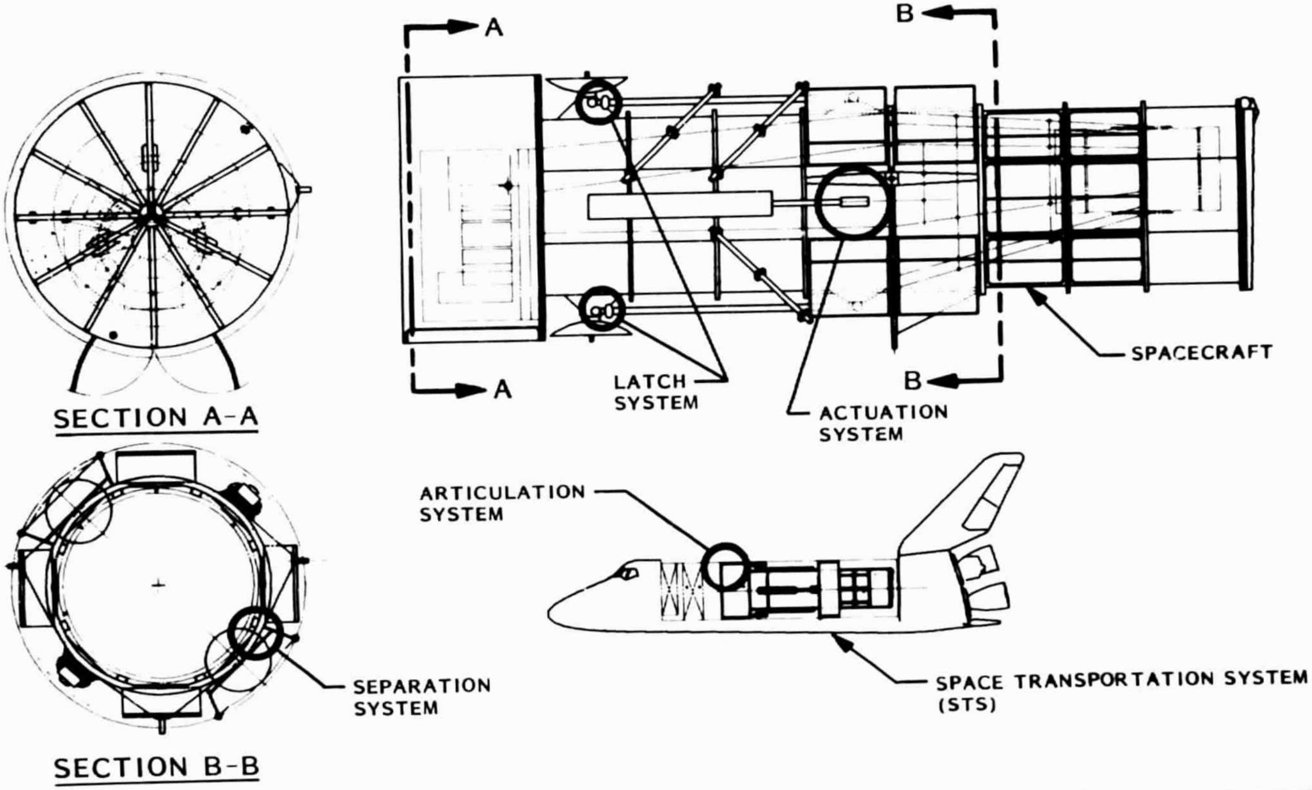
SECTION 4.0

MECHANICAL ELEMENTS



4.0 MECHANICAL ELEMENTS

4.1 General

The intent of this section is to describe various types of mechanical systems and devices typically associated with spacecraft operations and to establish requirements and guidelines for EVA interface with these systems.

4.2 Mechanism Description

Generally, spacecraft mechanisms fall into one of the following four systems:

- Retention
- Articulation
- Actuation
- Separation.

Each system may be either motor-actuated or manually driven.

4.2.1 Retention Systems. One example of a retention system is a latch used to retain an appendage within the launch envelope. In such systems, appendage deployment is generally the result of a sequence of events commanded and controlled from the ground. These systems are designed to withstand launch loads produced at the spacecraft/appendage interface.

Many instruments inside a spacecraft are preloaded into its supporting structure to ensure alignment. Mechanisms of this type are manually actuated and require precise torquing to ensure proper alignment and loading.

4.2.2 Articulation Systems. Articulation systems are used to point a device. These systems can be either linear (which would move a device on a predescribed path or track) or rotational (such as an antenna pointing gimbal). Mechanisms of this type would not normally require an EVA interface unless they interfered with launch envelopes or other EVA interfaces.

4.2.3 Actuation Systems. Actuation systems are closely associated with deployment of appendages. These systems are normally motor-driven by ground command and are used, for example, to erect masts for antennas and solar arrays.

4.2.4 Separation Systems. These systems are normally remotely controlled, such as a fluid or electrical power umbilical. Systems of this type are particularly hazardous to EVA operations due to spring-loaded retention devices that could retract the umbilical.

4.3 EVA Requirements for Mechanism Operation

4.3.1 Loads

4.3.1.1 EVA overrides should not require the application of more than 40 pounds of force to a 1-foot long handle (ratchet wrench).

4.3.1.2 Motors directly coupled to the system should not add to the above load. If they do, the motors must be uncoupled from the system by an additional EVA interface.

4.3.1.3 Surrounding structure should be designed for crewmember interface loads.

4.3.2 Operation

4.3.2.1 All mechanisms should be designed to facilitate verification of operation completion. Verification can be obtained by use of alignment marks at the tool interface, by a firm stop reached in the mechanism, by reaching a predetermined torque value, or by significant position of the mechanism.

4.3.2.2 Mechanisms that reach a stop by the breakage of a part should be avoided.

4.3.2.3 All interfaces and operating instructions should be clearly marked on the mechanism.

4.3.2.4 If a sequence of operations is required to override a mechanism, this sequence should be clearly indicated at the interfaces.

4.3.2.5 In the event of a failure in remote mechanism sequential operations release precautions should be taken to ensure that the system will continue to operate during override.

4.3.2.6 Mechanisms that require overrides should be designed to ensure that override operations can be accomplished with minimum ratchet wrenching.

4.3.3 Interface

4.3.3.1 All mechanisms should utilize a standard 7/16-inch hex interface.

4.3.3.2 All operational interfaces should be accessible to the EVA crewmember (see Fig. 4.3-1).

4.3.3.3 Mechanisms that require the use of special tools should be avoided.

4.3.4 Safety

4.3.4.1 During EVA, potentially unsafe operations (such as high-intensity communication of antennas) should be restricted.

4.3.4.2 Mechanism design should avoid the use of spring-loaded or pyrotechnic devices for deployment.

4.3.4.3 Mechanisms that use a spring retention device (i.e., an umbilical retention negator spring)

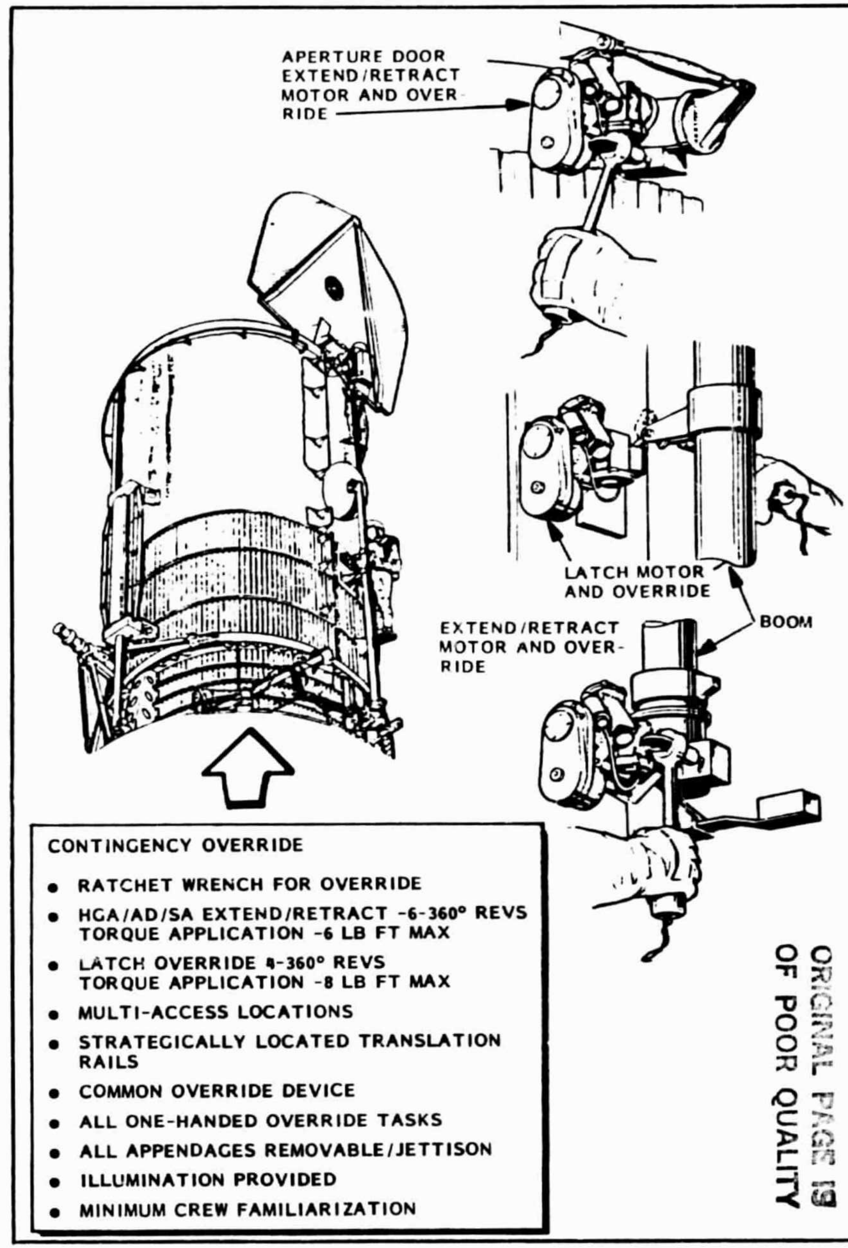


Fig. 4.3-1 Manned EVA Override Interfaces

should include an additional override to preclude sudden actuation of the system.

4.3.4.4 Mechanism systems should be designed to preclude entrapment.

4.3.5 Jettison

4.3.5.1 Jettison of appendages should be utilized only as a last resort if the creation of a suitable envelope for Earth return is required.

4.3.5.2 Appendages should be jettisonable in any operational condition.

4.3.5.3 Handholds should be designed into the appendage, as necessary, to aid in manual jettison.

4.3.5.4 All appendages must be clearly marked relative to their respective centers of gravity.

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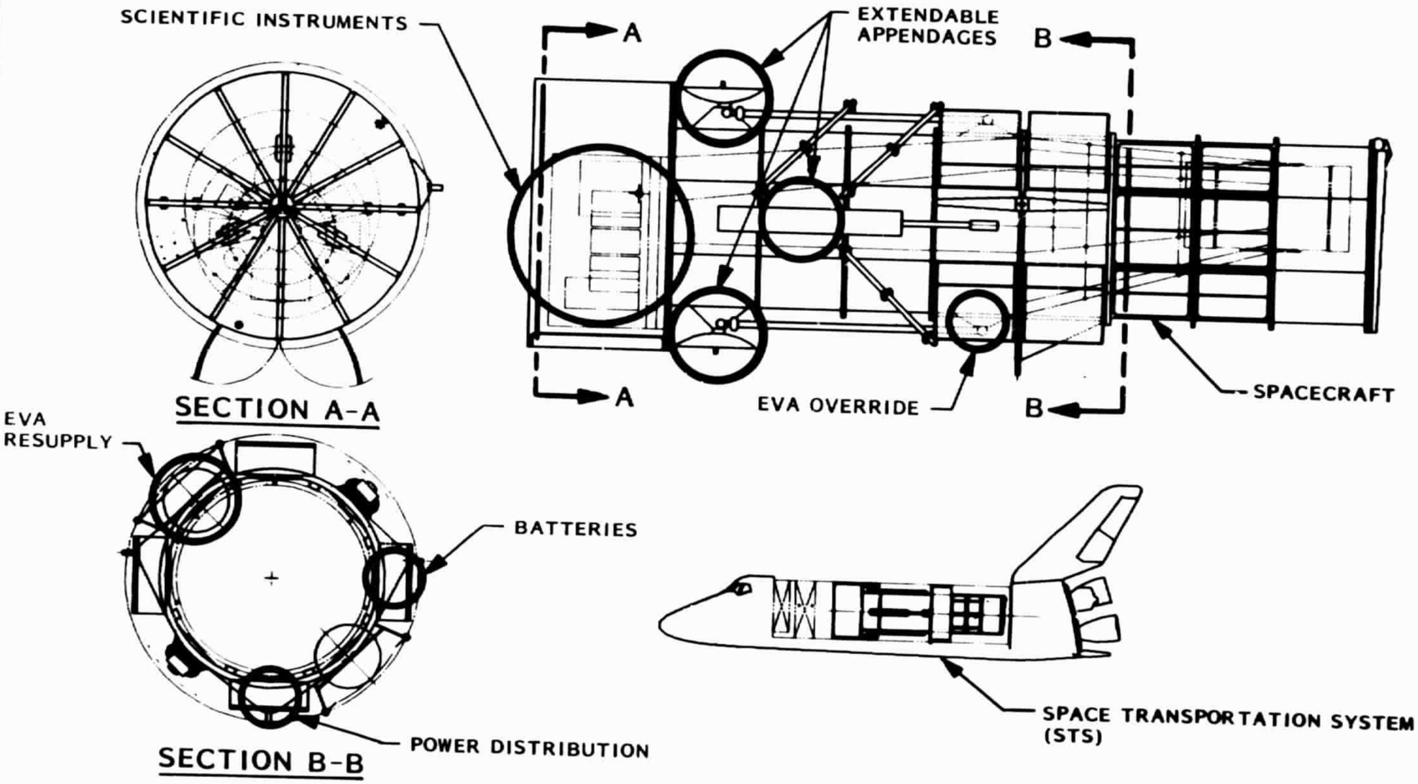
SECTION 5.0
DESIGN FOR CREW INTERFACE



5.0 DESIGN FOR CREW INTERFACE

5.1 General

Development, evaluation, and qualification of EVA support systems, equipment, and man-machine interfaces has evolved through the Gemini, Apollo, and Skylab space programs. This process has standardized various EVA operational techniques and hardware design criteria into the current Space Transportation System (STS) capabilities. This section will focus on current capabilities and constraints of a suited crewmember and how they affect satellite servicing.

5.2 Anthropometry

The following anthropometric dimensions outline the constraints of a suited crewmember through the full range of articulating motion.

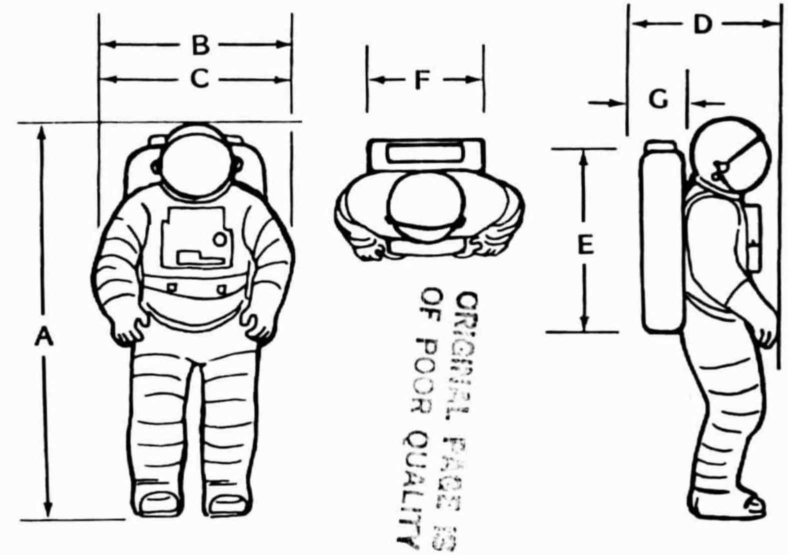
5.2.1 Figure 5.2.1 illustrates the average physical dimensions of a suited crewperson from the 5th percentile female to the 95th percentile male.

5.2.2 The EMU joint mobility limits are illustrated in Fig. 5.2-2. For quick reference, the same information is supplied in Table 5.2-1.

5.2.3 The EMU-suited crewmember's reach envelope to the side, fore, and aft is illustrated in Fig. 5.2-3.

5.2.4 The crewmember in a 0-g environment assumes a unique position when at rest. Figure 5.2-4 illustrates the neutral body position assumed by a male crewmember.

5.2.5 The EMU helmet provides the crewmember with self-adjustable lighting (108 lux at 2 feet) and the capability for a realtime S-band link to the Space Shuttle's CCTV system for procedure verification and problem assessment.



	SUIT DIMENSIONS SIZE RANGE: 5TH PERCENTILE FEMALE	SUIT DIMENSIONS SIZE RANGE: 95TH PERCENTILE MALE	LIFE SUPPORT SYSTEM DIMENSIONS
A - HEIGHT	171.5 (67.5)	191.8 (75.5)	E - HEIGHT 81.3 (32)
B - MAXIMUM BREADTH AT ELBOWS (ARMS RELAXED)	- -	74.7 (29.4)	F - BREADTH 58.4 (23) G - DEPTH 17.8 (7)
C - MAXIMUM BREADTH AT ELBOWS (ARMS AT SIDE)	- -	67.1 (26.4)	
D - MAXIMUM DEPTH WITH PLSS/SOP	66.0 (26.0)	72.1 (28.4)	

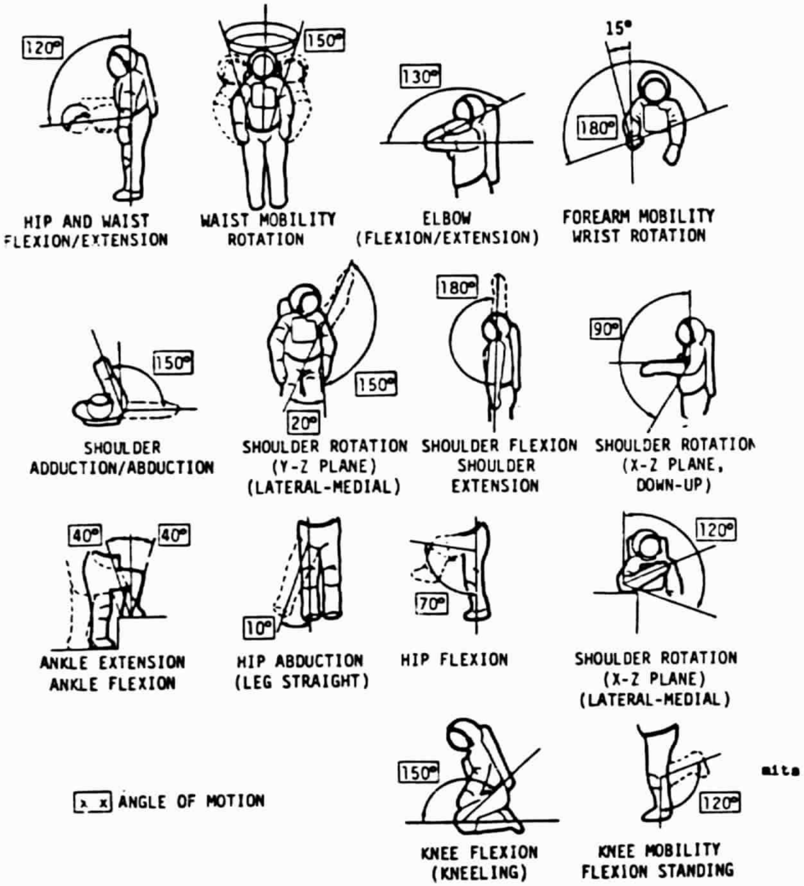
ALL DIMENSIONS IN CENTIMETERS WITH INCHES IN PARENTHESES.

PLSS - PRIMARY LIFE SUPPORT SYSTEM.

SOP - SECONDARY OXYGEN PACK.

REFERENCE 15

Fig. 5.2-1 Physical Dimensions of Suited (EMU) Crewmember



REFERENCE 14

Fig. 5.2-2 EMU Joint Mobility Limits

		MOBILITY RANGE (DEGREES)
A.	SHOULDER MOBILITY	
	ADDUCTION/ABDUCTION	150
	LATERAL/MEDIAL	20/150
	FLEXION/EXTENSION	180
	ROTATION (X-Z PLANE)	90
	ROTATION (Y-Z PLANE) (LATERAL-MEDIAL)	120
B.	ELBOW MOBILITY	
	FLEXION/EXTENSION	130
C.	WRIST MOBILITY	
	FLEXION/EXTENSION	90
	ADDUCTION/ABDUCTION	120
D.	WAIST MOBILITY	
	FLEXION/EXTENSION	90
	ROTATION	150
E.	HIP MOBILITY	
	FLEXION	70
	ABDUCTION	10
F.	KNEE MOBILITY	
	FLEXION (STANDING)	120
	FLEXION (KNEELING)	150
G.	ANKLE MOBILITY	
	FLEXION/EXTENSION	40/40
H.	FOREARM MOBILITY	
	WRIST ROTATION	180
I.	GLOVE MOBILITY	
	FINGER FLEXION/EXTENSION	GRASPING

REFERENCE 15

TABLE 5.2-1 EMU JOINT MOBILITY

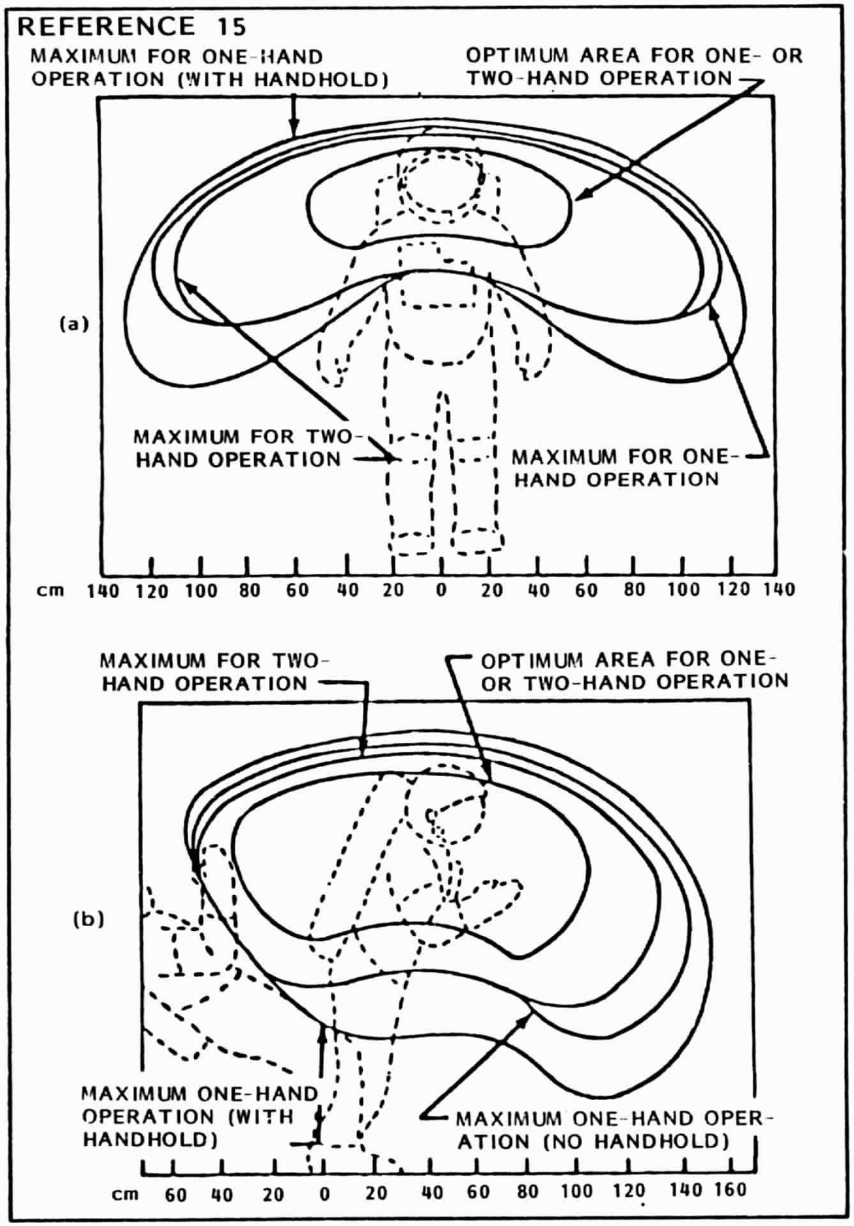


Fig. 5.2-3 EMU Crewmember Reach Envelope
(a) Side Reach (b) Fore-Aft Reach

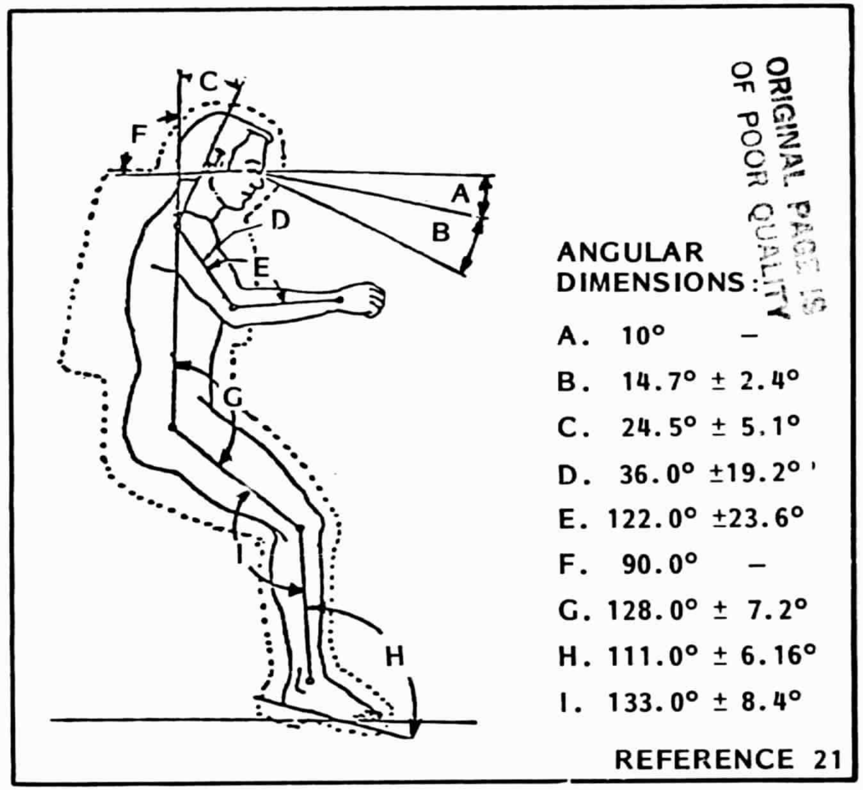


Fig. 5.2-4 Weightless Neutral Body Position, Male Crewmember

5.3 Work Envelopes

The following guidelines define crewmember work envelopes for translation, body entrance, gloved hand clearance, etc., and should be considered minimum acceptable design limits.

5.3.1 The suggested minimum translation corridor for EV crewmembers with full EVA gear should be a 40-inch diameter circle, both for straight-line translation through hatches and tunnel-like structures and for free-floating movement without the use of translation aids (see Fig. 5.3-1).

5.3.2 The recommended corridor size for fully suited EV crewmembers who require the use of mobility aids (i.e., handrails) should be at least a 43-inch-diameter circle (see Fig. 5.3-2).

5.3.3 When abrupt changes in direction of travel are required (more than 30 degrees in 9 ft) or when manipulative EV tasks are to be performed, a minimum working envelope of a 48-inch-diameter circle is suggested (see Fig. 5.3-3).

5.3.4 A maximum working envelope 8 inches wide by 18 inches deep has been established for the EV glove. This volume will allow a gloved hand to manipulate most hand-operated controls such as latches, switches, buttons, and knobs.

5.3.4.1 Compatible grasp surfaces should be provided for gloved-hand operations. Conformal/oval handles with knurled knobs and nonskid surfaces are preferred.

5.3.4.2 When gloved-hand clearance is required adjacent to ORUs, the following dimensions should be incorporated into the design.

- Clearance between ORUs, ORU/structure, ORU/cable, etc., should be at least 8 inches high, no more than 19 inches deep, and 10.5 inches wide.

5.3.5 When defining tool access volume and operational constraints, consideration should be given to the following guidelines.

5.3.5.1 When only tool access is required, a 1-inch minimum clearance should be provided around the fastener or drive stud for insertion, actuation, and removal of the drive end of the tool.

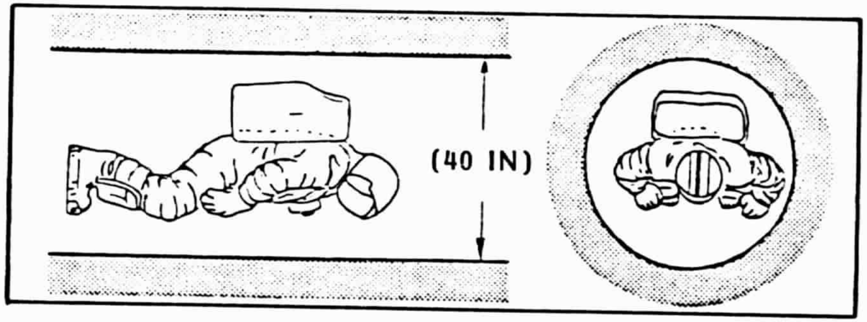


Fig. 5.3-1 Minimum Recommended Corridor for Unaided (No Handrails) Straight-Line Translation (Ref. 15)

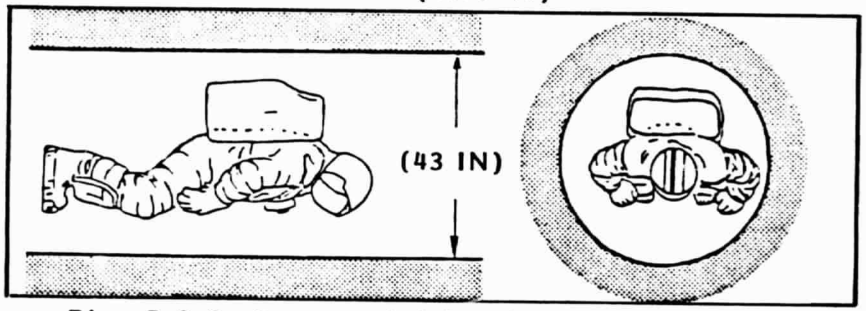


Fig. 5.3-2 Recommended Corridor for Handrail-Assisted Translation (Ref. 15)

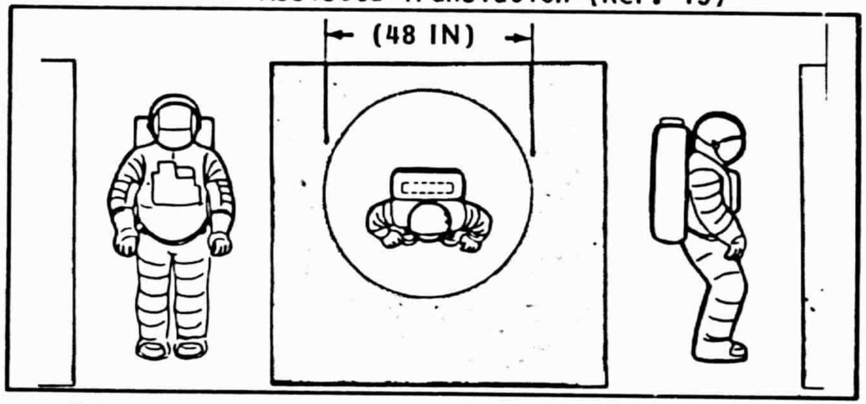


Fig. 5.3-3 Recommended Envelope for Manipulative EVA Tasks (Ref. 15)

5.3.5.2 A minimum of 3.0 inches should be provided for clearance between a tool handle engaged on a fastener or drive stud and the nearest piece of hardware (e.g., ORU box or handle). The tool handle should be able to maintain this clearance through a full 180° swept envelope.

5.4 Crew Loads/Forces and General Work Constraints

Spacecraft equipment that will be serviced by an EV crewmember (or spacecraft equipment that an EV crewmember may contact) must be designed to prevent damage to the crewmember and also must withstand crew-induced loads. This section describes crew-induced loads, forces, and work constraints associated with satellite servicing activities.

5.4.1 The primary life support system (PLSS) contains a sufficient quantity of consumables to provide the EV crewmember with 7 hours of independent life support. However, only 6 hours are allowed for nominal EVAs.

5.4.2 Table 5.4-1 depicts crew-induced loads that should be considered when designing servicing interfaces a crewmember will use or could come in contact with. For example, the ultimate load of 300 lb in any direction for a gloved-hand-induced load on an EV equipment tether/hook assembly, as compared with the working limit load of 100 lb, yields a 3X safety factor. This 3X safety factor is a recommended value for crew-induced loads but should not take precedence over contractual requirements.

5.4.3 When appropriate, electrical connectors should incorporate wing tabs for ease of operability by a gloved hand. Figure 5.4-1 illustrates a standard EV electrical connector.

TABLE 5.4-1 EVA CREW LOADS--SAFETY FACTORS

EV CREWMEMBER ACTIVITY	IMPOSED LOAD
• GLOVED HAND INDUCED LOAD ON EV WORK POSITION HANDHOLDS AND MOUNTING STRUCTURE	100 # LIMIT LOAD ANY DIRECTION 300 # ULTIMATE LOAD ANY DIRECTION
• GLOVED HAND INDUCED LOAD ON EV TRANSLATION HANDRAILS AND MOUNTING STRUCTURE	100 # LIMIT LOAD ANY DIRECTION 300 # ULTIMATE LOAD ANY DIRECTION
• GLOVED HAND INDUCED LOAD ON EQUIPMENT MOUNTED HANDHOLD (HANDLES) AND MOUNTING STRUCTURE (NOT USED AS EV PERSONNEL TETHER POINT)	100 # LIMIT LOAD ANY DIRECTION 300 # ULTIMATE LOAD ANY DIRECTION
• CREWMEMBER INDUCED LOAD ON EV FOOT RESTRAINT AND MOUNTING STRACTURE	100 # LIMIT LOAD, TENSION/SHEAR 300 # ULTIMATE LOAD, TENSION/SHEAR 1800 IN LB MIN TORSION ABOUT AXIS PREPENDICULAR TO FOOT RESTRAINT
• CREWMEMBER INDUCED LOAD ON EV PERSONNEL TETHER POINT AND MOUNTING STRUCTURE	300 # LIMIT ANY DIRECTION 900 # ULTIMATE LOAD ANY DIRECTION
• GLOVED HAND INDUCED LOAD ON EV EQUIPMENT TETHER POINT AND MOUNTING STRUCTURE	100 # LIMIT LOAD 300 # ULTIMATE LOAD
• CREWMEMBER INDUCED LOAD ON EV PERSONNEL TETHER/HOOK ASSEMBLY	300 # LIMIT LOAD TESNION 900 # ULTIMATE LOAD TENSION
• GLOVED HAND INDUCED LOAD ON EV EQUIPMENT TETHER/HOOK ASSEMBLY	100 # LIMIT LOAD 300 # ULTIMATE LAOD

REFERENCE 21

5.4.4 For electrical connectors that do not incorporate wing tabs, the following conditions apply.

5.4.4.1 All connector shells should be knurled and designed to prevent tear damage to the EV gloved hand.

5.4.4.2 Connector shells greater than 1.0 inch but less than 3.0 inches in diameter having a minimum 0.5-inch-wide rim surface that may be actuated during ground maintenance should not exceed the finger/thumb torque limits described in Table 5.4-2.

5.4.5 For ORU changeout, adjustment features and alignment patterns should be visually accessible to the EV crewmember without removal of any component.

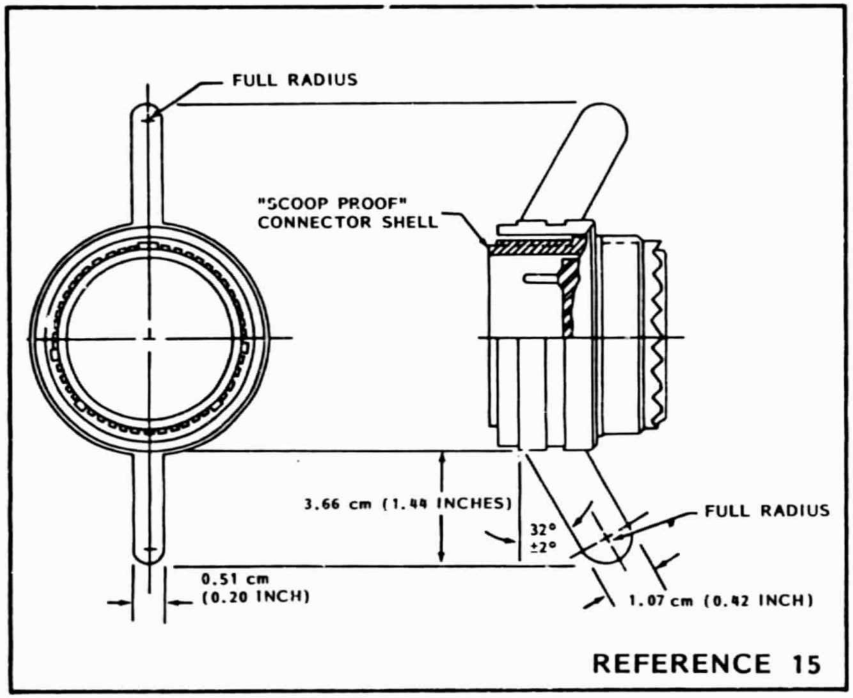


Fig. 5.4-1 EV Standard Connector

TABLE 5.4-2 CONNECTOR ACTUATION RESISTANCE, FINGER/THUMB TORQUE (Ref. 21)

Connector Diameter	Torque
1.0 in.	4.0 in.-lb
1.5 in.	5.6 in.-lb
2.0 in.	8.6 in.-lb
2.5 in.	12.4 in.-lb
3.0 in.	16.0 in.-lb (finger curl)
4.0 in.	24.8 in.-lb (finger curl)
5.0 in.	33.6 in.-lb (finger curl)

5.4.6 Wing-tabbed connectors should be spaced a minimum of 1.5 inches apart to allow for EV gloved-hand access (see Fig. 5.4-2). This spacing should be used for staggered as well as vertically aligned arrays.

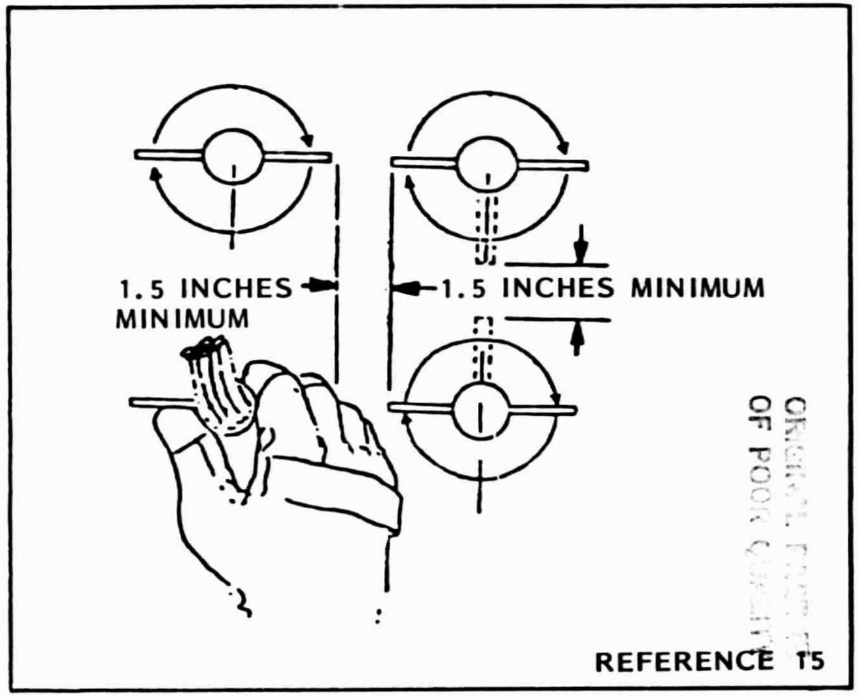


Fig. 5.4-2 Minimum Clearances Between Wing-Tabbed Connectors for EV Gloved-Hand Access

5.4.7 When possible, multiple rows of connectors should be avoided. For small ORUs, drive mechanisms should be substituted for hand activation when the number of connectors to that ORU exceeds three at one location.

5.4.8 When ORUs are located within enclosed areas, handles, attach/release mechanisms, etc., should be positioned as close to the existing plane of access as possible. This will facilitate both visibility and arm or gloved hand access.

5.4.9 Hinged access doors, including doors used to mount or park ORUs or SSE, should be capable of being secured in both fully open and fully closed positions.

5.4.10 A positive indication of proper door closure should be provided in the design of doors, access covers, or hatches that may be accessed by EV crewmembers.

5.4.11 Single-handed actuations should accommodate both right-handed and left-handed operations. Where such accommodation is not possible, operations should favor the right-handed user.

5.4.12 To ensure crew and equipment safety, and to prevent the possibility of snagging, tearing, or cutting the EV spacesuit, consideration should be given to the following surface texture finish guidelines included in Section 1.4.

5.4.13 The location of electrical safety controls should permit ready physical access, allow crewmembers to distinguish on/off positions clearly, and be protected to prevent inadvertent operation.

5.4.14 To minimize crew workload and maximize crew efficiency, planned mating and demating of connectors and movement of electrical cables by EV crewmembers should be conducted from a predetermined and restrained crewmember position.

5.4.14.1 When the number of interface connections is four or fewer and the connectors are readily accessible, hand actuation of electrical connectors should be permitted and governed by the following guidelines.

- Connectors that must be actuated during EVA should be located within the respective work space envelopes.

- Electrical connectors with an effective grasping diameter (i.e., shell plus wing tabs) greater than 3.0 inches but less than 5.0 inches may be hand-torqued, but should not exceed the EV gloved hand torque values as described in Table 5.4-3.

- Knurled connector shells 1.0 inch or greater in diameter (without wing tabs), but less than 5.0 inches in diameter and having a 0.5-inch-wide rim surface may be finger-torqued but should not require torque levels greater than specified in Table 5.4-4.

- Minimum clearances for hand-torqued connectors should be provided as depicted in Figure 5.4-2.

- The EV crewmember should not be exposed to active electrical circuits during connector mating and demating by hand. In cases where access to power cannot be avoided, safety interlocks, recessing of pins/contacts, and warning labels should be provided.

- Connector shells should have alignment guides to ensure proper plug/receptacle engagement and markings for connector mate and lock positions.

- All hand-actuated EV connectors should incorporate quick disconnect and single-locking actuation provisions.

5.4.15 Hand or tool-actuated drive mechanisms should not require gloved-hand force applications beyond the levels described in Table 5.4-3.

TABLE 5.4-3 MAXIMUM WORK FORCE APPLICATIONS, EV CREWMEMBERS (Ref. 21)

Load Description, Restrained Crewmember Actuations	Limit Load
• Gloved hand, steady-state force application	*25 lb
• Gloved hand, instantaneous or breakaway force	36 lb
• Gloved hand torque, wing tab connector	**50 in.-lb
• Gloved hand, single cycle hand squeeze	30 lb
• Gloved finger, toggle switch actuation	**0.63 to 6.25 lb
• Booted foot, toe-button detent (one foot restrained)	**4.0 to 20.0 lb

Note:

* The useful work involves a 10-Btu work output for a 5-min duration, interspersed with a rest period between applications.

** Force range includes a minimum value to ensure a resistance level for tactile feedback.

Table 5.4-4 CONNECTOR ACTUATION RESISTANCE, FINGERTIP, EV GLOVED HAND (Ref. 21)

Connector Diameter (in.)	Torque (in.-lb)
1.0	4.0
1.5	5.6
2.0	8.6
2.5	12.4
3.0	16.0 (finger curl)
4.0	24.8 (finger curl)
5.0	33.6 (finger curl)

5.4.16 A minimum 2-pound backdrive resistance force at the handle should be incorporated into the design of ORU rack and bracket securing release mechanisms.

5.4.17 Lock-and-stop positions required for final installation, tray connector disengagement, and intermediate positions that may be required for ORU replacement should be visually apparent to the EV crewmember.

5.4.18 When orbital maintenance activities require the EV crewmember to handle electrical cables or wire harnesses, the cables/harnesses should be designed and located as follows:

- Electrical cables, installations, and wire bundles should have sufficient flexibility and length (i.e., maintenance loops) to remove and replace units without cable interference.
- Cables and wire bundles should be configured, located, clamped, or supported to eliminate (a) mechanical stress or damage to wires and/or wire terminations and (b) deformation beyond the allowable radii established for a particular installation or removal operation.

5.4.19 Designs of electrical interfaces shall be compatible with the following crew and equipment safety requirements, as applicable:

- Connectors and cables exposed to inadvertent crew contact should be designed to accommodate loads as described in Table 5.4-4.
- Electrical interface components should be captive and restrained within envelopes specified for EV handling, stowage, installation, removal, restowage, and jettison activities.
- Lock wire should not be used on EV connectors.

5.4.20 Equipment exposed to inadvertent EV crewmember contact may be subject to loads as described in Table 5.4-5.

TABLE 5.4-5 MAXIMUM LOADS INADVERTENTLY IMPOSED BY CREWMEMBER (Ref. 21)

Load Description	Limit Load (lb)
Hand/arm forces on translation handholds, handrails, equipment tethers, and foot restraint attach points	*100
Safety tethers, personnel	300
Exposed electrical harnesses - gloved hand contact	20
Hand loading on wing tab connector/connector shells, inadvertent hand torque application of force to wing tabs	**50
Multilayered Insulation (MLI):	
• Push and impact (normal to covered surfaces)	100
• Tension	20

Note:

* Surfaces and structures within the normal EV crewmember access planes shall be constrained by this limit load.

** Assumes a shell diameter greater than 1 inch plus two 1-inch wing tabs.

5.4.21 Actuation or operation of equipment by an unrestrained (tethered but otherwise free-floating) EV crewmember should not require the application of forces and durations that exceed the following:

1.0 lb for 4.5 sec
5.0 lb for 2.1 sec
10.0 lb for 1.4 sec

Note: The maximum distance through which these forces may be applied is 16 inches.

5.4.22 The maximum elastic torque angle of twist allowed during EV application of force should be 15 degrees beyond the angle of rotation/actuation of the tool or device used. This allowance should be retrained within the allowable work, stowage, and access envelopes.

5.5 Mounted Crew Aids

This section establishes the requirements for the location and design of mounted crew aids used during orbital maintenance by EV crewmembers.

Crew aids, as defined herein, are hardware or equipment permanently attached to the spacecraft structure (i.e., mounting brackets, blocks, channels, edges, guards, guides, inserts, latches, rails, shields, sockets, standoffs, and stops) used to support EV crewmember operations.

5.5.1 Whenever possible, mounted crew aids should be planned and designed to be an integral part of structural, mechanical, thermal, and electrical power subsystems, and should be coordinated with the EV crew system requirements defined herein.

5.5.2 Mounted crew aids should be placed (a) to support the broadest range of EV operations possible within the minimum EV workspace and (b) to require a minimum amount of adjustment by the EV crewmember (see Fig. 5.5-1).

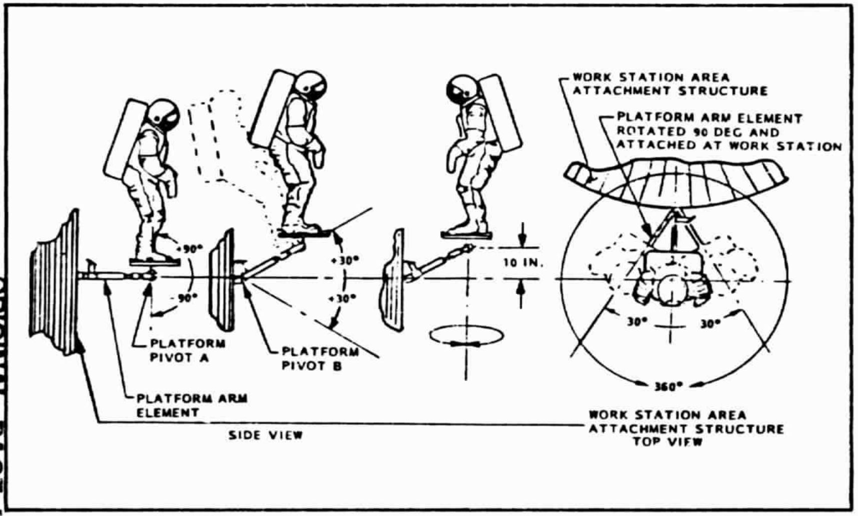


Fig. 5.5-1 Use of Crew Aids Increases EV Crewmember Work and Reach Envelopes

5.5.3 All mounted crew aids should incorporate the following general provisions, as applicable.

5.5.3.1 Permanently mounted crew aids should accommodate EV crew imposed loads as indicated in Table 5.4-5 and be compatible with limit envelopes as described in Fig. 5.2-3.

5.5.3.2 Deployable and extendable aids having the potential to project hardware or structures beyond the cargo bay/payload stowage envelope and into the 48 inch egress area from the airlock should have jettison provisions.

5.5.3.3 Crew aids used to mechanically guide, position, or limit the articulation of equipment during EVA should maintain a 0.5 inch clearance between the equipment supported and adjacent equipment or structures, unless specific physical stops or guides are provided that can accommodate both planned and inadvertent crew imposed loads and displacements.

5.5.3.4 Where crew aids must accommodate more than one item of equipment or support various attitudes and where these settings may be critical for a specific operation, they should be clearly marked or distinguished and, as a goal, permit the EV crewmember to select and secure to each setting without the use of tools.

5.5.3.5 Where crew aids require locking or latching, the mechanisms should be designed to be operable by minimum actuation activity and provide a clear visual indication of whether the latch or lock position is opened or closed.

5.5.4 Stability and restraint of EV crewmembers and replacement/support hardware at each maintenance work site should be accomplished as follows:

5.5.4.1 Foot restraint receptacles should be provided and designed to incorporate the following specific features:

- EV foot restraint receptacles should be located to provide support to the EV crewmember throughout the reach envelope at the maintenance work site.

- EV foot restraint receptacles should use a common mounting attachment design to enable rapid interchangeability of the foot restraint throughout the spacecraft.

5.5.4.2 Mounted handrails and handholds used as translation and mobility aids and to stabilize or hold temporary positions by EV crewmembers should be designed as follows:

- Mounted handrail and handhold locations should be compatible with translation between the spacecraft and the Orbiter-provided handrails and handholds.

- All EVA handholds and handrails should use the designated Orbiter color (yellow, 23785), rail cross-section, and have a standardized physical appearance.

- Handrails along translation routes should not be separated end-to-end by more than 24 inches.

5.5.4.3 Spacecraft mounted tether attach points should be designed and located as follows:

- Equipment and personnel tether loops should be distinguishable from one another, be located/oriented for EV crew visibility, and have a minimum 1.3-inch opening to accommodate a positive engagement of tether hook and fitting.

- Spacecraft-mounted tether points should be located as follows:

  - At the extreme ends of equipment transfer paths

  - At either side of the foot restraint centerline at each specific changeout or workstation location

  - At 48 inch (or less) intervals along all EV translation paths about the spacecraft

  - At either side of a directional change in equipment transfer or a distinct hand-off point.

5.6 EVA Fasteners and Attachment Systems

This section establishes guidelines for the design, selection, and location of EV fasteners and attachment systems that may involve EV crew interface.

5.6.1 The design should provide for actuation of fasteners and attach systems from predetermined crew work positions.

5.6.2 Access to EVA/ORU attach/restraint devices and fasteners should not require removal of permanently installed covers (or covering materials) or fixed structural elements nor, as a goal, of other adjacent equipment.

5.6.3 Hand actuated attach systems (including knobs, levers, latches, rings, clamps, etc.), if used for EVA/ORU designs, should be designed in compliance with requirements equivalent to those imposed on hand actuated connectors.

5.6.4 Key or tool-actuated attach/restraint systems should comply with the following requirements:

5.6.4.1 To reduce EVA orbital maintenance time and, wherever possible, to reduce the variety of tools and crew aids, fasteners that require actuation during orbital maintenance operations should be selected and used as follows:

- Where standard 0.25 inch ORU bolts are used, a standard torque wrench setting of 90 to 110 in-lbs should be used. Other tool actuated attachment and drive systems should be governed by the gloved hand forces described in Section 5.4.16.

- External grip, single diameter fastener heads should be used to allow actuation using one type of tool and minimize the requirements for different socket adapters.

- The depth of access to key or tool actuated attachments should, wherever possible be standardized to minimize the number of extension lengths needed and EVA mission time.

5.6.4.2 Tool actuated attach/restraint systems should not require the restrained EV crewmembers to apply gloved hand forces greater than the limits set forth in Table 5.4.3.

5.6.4.3 Tool actuated attach/restraint systems should not require the unrestrained EV crewmember to apply forces for the short duration or limits that exceed the limit capabilities set forth in Section 5.4.22.

5.6.5 Designs of attachment systems used in on-orbit replacement should be compatible with the following crew and equipment constraints.

5.6.5.1 EV actuated fasteners/devices should be visually accessible to ensure proper seating or restraint in stowed, parked, or installed locations.

5.6.5.2 EVA/ORU restraint/attach systems planned to be removed should be selected, located, or uniquely identified to preclude inadvertent removal of non-EVA/ORU fastener systems.

5.6.5.3 All fasteners and attachment elements (including sleeves, nuts, spaces, washers, springs, inserts, pins, and keys) should be captive and restrained, preferably to the spacecraft side of the attaching interfaces. For jettisonable equipment, such elements should be captive or restrained to the jettisoned item side.

5.7 EVA Lighting, Illumination, and Visibility

This section establishes the lighting, illumination, and visibility requirements for EV crewmembers during both planned and unscheduled orbital maintenance activities.

5.7.1 Adequate illumination should be provided to ensure that all EV crew activities will be performed in a safe, efficient, and timely manner during conditions of both sunlight and shadow.

5.7.1.1 As a design criterion for the provision of EV lighting, power and weight minimization should be stressed.

5.7.1.2 EV lighting systems should be redundant to ensure that, in the event of a component lighting failure, adequate illumination will be available to allow the EV crewmember to safely return to the Orbiter (as a minimum) and/or to complete his tasks.

5.7.1.3 Lighting systems used by EV crewmembers should (a) satisfy the minimum illumination requirements as specified in Table 5.7-1, and (b) take into consideration the characteristics of the light sources described in Table 5.7-2.

5.7.1.4 Work areas in which EV tasks will be performed should be provided with light sources which are adjustable in terms of both intensity and directionality by the EV crewmember.

5.7.1.5 EV lighting system should be designed to minimize glare by:

- Employing diffused lighting, wherever possible

- Providing glare shields for glare-producing light sources

TABLE 5.7-1 ILLUMINATION REQUIREMENTS(MINIMUM)(Ref.21)

Location	Level
Translation Paths	3 ft-c
Work Task Areas:	30 ft-c
• Installation/Removal	
• Fastener Engagement/ Disengagement	
• Control Operation/ Actuation	
• Manual Override/ Jettison	
Safety Critical Areas	50 ft-c

Note: Low brightness ratio enhances visual acuity. Therefore, as a design goal, the design of workstations should limit the brightness ratio between work surfaces and background to 3:1 or less.

- Locating light sources beyond 60° of the center of the EV crewmember's field of view (at EV task areas).

5.7.1.6 To preclude the occurrence of specular glare, the use of smooth, highly polished surfaces within the EV crewmember's field-of-view at EV work areas should, wherever possible, be avoided.

5.7.1.7 The use of Orbiter attitude to satisfy the lighting requirements for EV work activities should be avoided.

5.7.1.8 A portable light may be used for emergencies, unplanned maintenance, and task performance in areas where adequate fixed illumination is not available.

TABLE 5.7-2 LIGHT SOURCE CHARACTERISTICS (Ref. 21)

Cargo Bay Lights	Helmet Lights
Cargo Bay Floodlights (6)	Four Lights
Watts - 130 (available)	4 bulbs
Lumens/	23 ft-c (total)
Watt - 40 (minimum)	at 5 ft
Type - Arc Discharge	
Beam - 135° x 120°	
Forward Bulkhead Lights (1)	Two Lights
Watts - 130 (available)	18 ft-c
Lumens/	at 5 ft
Watt - 40 (minimum	
Beam - 120° x 120°	
Overhead/Docking Light (1)	Note: After 6
Watts - 130 (available)	hours the total
Lumens/	illumination out-
Watt - 12 (minimum)	put generated by
Beam - 120° x 120°	these lights will
RMS Light (1)	have degraded by
Watts - 150	approximately 20
Lumens/	percent.
Watt - 12 (minimum)	
Beam - 80°	

5.7.1.9 All "on-off" switches for lights that are used to illuminate designated EV work areas should be located within the general activity envelopes defined by those areas. In addition, for EV light switches employed in the control of illumination within confined environments, the following requirements should apply:

- EV lights located within confined environments should have their associated control switches located as close to their enclosure entrances as possible.

- A method for on-orbit control of power should be provided to allow the EV crewmember to remove power from spacecraft-mounted lighting systems as part of the closeout routine following orbital maintenance activities.

5.8 EV Labeling, Marking, and Color Coding

This section establishes guidelines for the design, selection, and use of labels, markings, and color codes for equipment and structures with which crewmembers may interface during EV operations.

5.8.1 The use of labels, markings, and color codes should be standardized for orbital maintenance operations and should be considered required supplements to EV crew aids for the following functions:

- To identify specific equipment or structures and/or to describe equipment functions and interfaces
- To indicate potentially hazardous equipment, locations, or conditions
- To indicate pre-installation attitudes and installation/removal travel, excursion, or maneuvering dynamics
- To indicate proper alignment, interface, and removal/replacement sequences
- To identify parking, work support, and staging positions during on-orbit replacement/changeout
- To indicate stowage locations and attitudes for EV crew aids and orbit replaceable units (ORU)
- To identify the contents of enclosures and containers
- To indicate direction and/or excursion of equipment during EV operation.

5.8.2 Labeling and Marking

5.8.2.1 EV labels and markings should be placed on, or very near to, the items which they identify and be visible to the EV crewmembers.

5.8.2.2 Uppercase (capital) lettering should be used for all labels and markings, except abbreviations and symbols for which lower case letters are the commonly accepted practice (i.e., O_2, He, pH, Hg).

5.8.2.3 All labels should use simple, unadorned font styles. (Sans serif font styles are preferred.)

5.8.2.4 The height of letters and numerals selected for use on EV labels should not be less than 0.12 inch when viewed from a standard viewing distance of 28 inches.

Note: For greater viewing distances:

$$\text{Minimum character height} = \frac{(A)(0.12 \text{ in.})}{28 \text{ in.}}$$

where A = new viewing distance (in.)

5.8.2.5 Subscripts and lowercase letters should be between 60 percent and 70 percent of the height of associated characters.

5.8.2.6 Wherever possible, labels should be spelled out rather than abbreviated. Where spacecraft-peculiar abbreviations are used, crew training and procedures will be documented to ensure correct understanding.

5.8.2.7 Adequate visual contrast should be provided between labels/markings and their background under the lighting conditions provided.

5.8.2.8 Alignment Marks

- Where the proper mounting orientation of orbital replacement units is not obvious but is critical to its operation, alignment marks in addition to alignment aids should be provided.

- Where there is a requirement to mate electrical plugs to their receptacles, alignment marks should be used to indicate the proper engagement and locked positions, preferably at the interface.

- Alignment marks utilized to ensure proper mounting orientations should consist of straight lines having a minimum length of 0.40 inch and a minimum width of 0.125 inch. Alignment marks used to ensure proper electrical interface should consist of straight lines having a minimum length of 0.30 inch and a minimum width of 0.125 inch.

- When a piece of hardware requires a special orientation that is not immediately obvious by use of the alignment marks, arrows shall be used to indicate the proper spatial orientation.

5.8.3 Color Coding

5.8.3.1 In general, color codes should be used only when adequate illumination is available. Color coding should not be used if the quality of the ambient light provided during maintenance operations varies significantly.

5.8.3.2 If color coding is required, only the colors identified in FED-STD-595 should be used. Controls should be black (17038) or gray (26231); other colors used to facilitate orbital maintenance activities are as shown in Table 5.8-1.

5.8.3.3 Caution and warning labels should comply with the following color requirements:

Topic	Characters	Background	Border
Caution	Black	Orange-yellow	Black
Warning	White	Red	White

5.8.3.4 Control/display panel labels should comply with the following color requirements:

Characters	Background
White	Gray

5.8.3.5 If color coding is used to relate a control to its corresponding display, the same color should be used for both the control and the display.

TABLE 5.8-1 STANDARD COLOR CODING USE (Ref. 21)

Standard Use	Color	FED-STD-595 #
Emergency, warning, danger; safety controls; controls requiring rapid identification	Red	11105, 21105
Caution; safety controls associated with emergencies of a less critical nature	Orange-Yellow	13538, 23538
Safe condition; operations having no urgent or emergency implications	Green	14187, 24287
Separation, contrast or delineation on dark surfaces with above colors	White	17875, 27875

5.8.3.6 Coding on the face of display scale indicators should be used to convey such information as a desirable operating range, continuous operating range, dangerous operating level, undesirable condition, and/or caution indication.

5.8.3.7 Colors selected for use with controls, displays, handholds, handrails, and foot restraints should provide adequate visual contrast with their backgrounds under the lighting conditions provided. (Contrast ratios of 10:1 are recommended for handrails, handholds, and foot restraints.)

5.8.4 Labeling, Marking, and Color Coding Applications

5.8.4.1 Equipment Identification

- Except for items whose use is obvious to the crewmembers, equipment that must be located, identified, observed, operated, and/or moved by an EV crewmember should be labeled or marked with nomenclature identifying the equipment and, as appropriate, describing its function and pertinent interfaces.

- For wing tab connectors used at EV workstations, both halves of each connection should display a label or code that is unique to that connection. (Discrete nomenclature or alphanumeric coding should be required coding for this purpose.)

- When used for EV demating and remating of electrical interfaces, tools and hand-operated devices should be labeled or marked so as to make function and direction of actuation obvious.

- The difference between personnel and equipment tethers should be readily apparent. The designs of either should become separately standardized in configuration and color to avoid confusion by EV crewmembers to aid EVA training, and to clarify procedures.

- A method should be provided to identify failed or expended items (i.e., equipment, connectors, controls, displays) and to visually recognize unusable items.

- All handholds and handrails used by EV crewmembers should be colored yellow (23785) as specified in FED-STD-595.

5.8.4.2 Cautions and Warnings

- Caution and warning labels should be used to denote potentially dangerous equipment or conditions which might result in crew injury, hardware damage, or mission failure.

- Potentially hazardous displacement or movement of large appendages or ORUs that could occur during EVA should be labeled and made visually apparent to the EV crewmember.

- Edges and protrusions that cannot be made safe due to operational reasons should be provided with caution or warning labels and crew protection.

5.9 EV Controls and Displays

This section establishes guidelines for the design, selection, and location of controls and displays (C/D) provided in support of orbital maintenance operations by EV crewmembers.

5.9.1 Control Requirements

5.9.1.1 Maximum control displacement spans for fully restrained EV crewmember should be limited to the

dimensions listed in Table 5.9-1.

5.9.1.2 The minimum resistance to ensure tactile feedback during control actuation should be 2 lb for hand controls and 4 lb for foot-actuated controls (i.e., button detent). Where intermediate or stop positions are required, detents should be provided.

5.9.1.3 Crewmembers should be provided with a positive indication (i.e., flags, indicator lights) that operation of equipment by control inputs associated with discrete positions has been, or is in the process of being, executed.

TABLE 5.9-1 HAND AND FOOT ACTUATION/DISPLACEMENT LIMITS, EV CONTROLS (Ref. 21)

Displacement Maneuver	Displacement Span (in.)
Hand movement, lateral (side-to-side)	38.0.
Hand movement, forward/backward	14.0.
Hand movement, upward/downward	27.0.
Rotary hand movement (swept circular motions, any place of rotation)	-8.0.
Foot displacement, ankle flexion, heel in place (20°)	2.5 max.
Foot displacement, one foot fixed lateral spacing	2.0 min.
Foot displacement, leg lift (one foot restrained)	7.0 max.

5.9.1.4 Controls which result in system shutdown to a non-critical operating state when force is removed should be used wherever crewmember incapacity can produce a critical system condition.

5.9.1.5 In no case should a ground maintenance control be located in the same area occupied by controls used during EVA operations.

5.9.1.6 Design and operational procedures should ensure that all IV and/or ground-directed controls for which EV control duplicates exist are made safe against inadvertent IV or ground actuations during EVA.

5.9.2 Switches

5.9.2.1 All finger-actuated switches (including rocker switches, rotary switches, and toggle switches) should be provided with a minimum resistance of 10 ounces to ensure adequate tactile feedback when using pressurized EV gloves.

5.9.2.2 Toggle Switches

- As a goal, toggle switches should be used only for control functions in which two discrete control positions are required.
- When three-position toggles must be used, the switch should be accompanied by a position indication. In addition, if an "OFF" indication is required, toggle switch design should associate the "OFF" function with the central position, except where this would compromise equipment performance.
- As a goal, toggle switch design should preclude the ability to stop between individual control positions.
- Toggle switch handles should be a minimum of 1 inch and a maximum of 2 inches long.
- A minimum of 1.5 inches should be provided between toggle switches and adjacent switches/structures.

Note: Whenever possible, multiple rows of toggle switches should be avoided.

5.9.3 Displays

5.9.3.1 Display faces should not be oriented more than 45 degrees from the EV crewmember's line-of-view while in his normal viewing position.

5.9.3.2 As a goal, the effective viewing distance to displays should not be less than 20 inches.

5.9.3.3 Display information should (a) be limited to that necessary for the crewmember to perform specific actions or to make decisions, (b) as a goal, be simultaneously nonredundant, and (c) be presented in an unambiguous and directly usable form.

5.9.3.4 Flags

- Flags should be mounted as close to the panel surface as possible without restricting their movement or obscuring necessary information.

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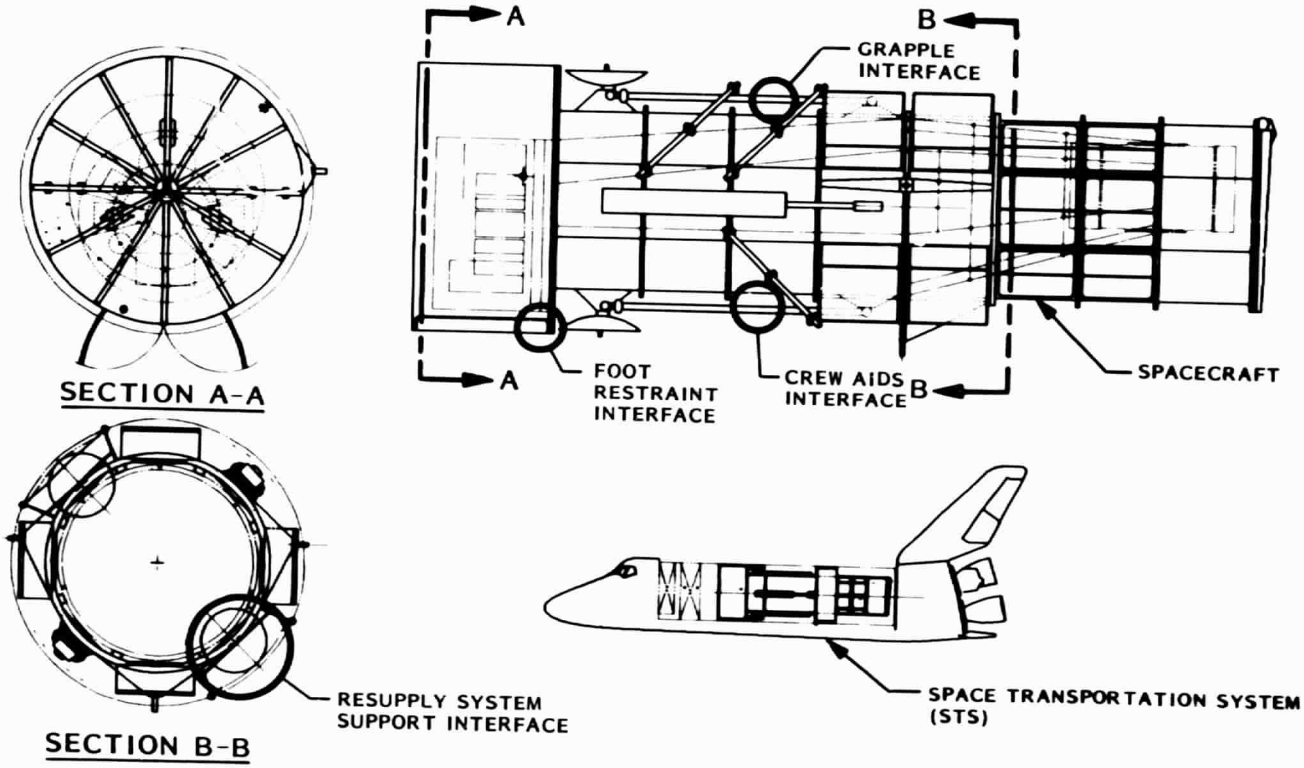
SECTION 6.0
AIRBORNE SUPPORT EQUIPMENT (ASE)



6.0 AIRBORNE SUPPORT EQUIPMENT (ASE)

6.1 General

For the purposes of this document, ASE is defined as equipment, structures, components, boxes, cradles, etc., that are not part of the spacecraft (not attached to spacecraft), but that act to support spacecraft systems and subsystems. Various categories and types of standard ASE are listed in Table 6.1-1.

6.2 Mounting Interfaces

6.2.1 Crew Aids. When appropriate, crew aids used for satellite servicing should be incorporated into the design of ASE to provide an override capability. Typical examples include handrails, handholds, tethering devices, foot restraints and workstations. Design guidelines for crew aids are referenced in Section 5.0 (Design for Crew Interface).

6.2.2 ORUs. There are many guidelines that should be considered before an ORU or ASE is mounted to a spacecraft (i.e., experiment package configuration, footprint, attachment systems, repair accessibility, handleability, cable/connector interfaces, grounding systems). Detailed guidelines relative to these interfaces are provided in Section 2.0 (Design of Orbital Replaceable Units).

6.2.3 Cable Line Management. ASE that interfaces with a spacecraft will require an electrical power system which is designed to prevent hazardous EV operations. Connectors should be of an approved type, spacing and mating of connectors standardized, and cable runs secured every 18 inches. Detailed guidelines associated with the design of these interfaces are presented in Section 2.0.

6.2.4 Loads. ASE should incorporate mounting interface design features which are compatible with

TABLE 6.1-1 CATEGORIES OF ASE

A. Tools/Aids
- Foot Restraints
- Standard EVA Tools
- EVA Contingency Tools
- Manned Maneuvering Unit (MMU)
- Orbital Transfer Vehicle (OTV)
- EV Translation Aids

B. Support Structure
- Spacecraft Support Cradle
- Support Equipment Restraining/Holding Devices
- EV Equipment Storage Containers

C. Active/Passive Mechanisms
- Retention Latches (PRLAs)
- Tilt Tables
- Holding and Positioning Aids (HPA)
- Remote Manipulator System (RMS)
- Spin Tables
- Payload Insertion Deployment Aids (PIDAs)

D. Display/Control Subsystem Panel
- Gauges
- Meters
- Markings
- Panel Types

E. Electrical Signal Devices
- Cables
- Umbilicals
- Connectors

F. Fluid/Gas Transfer Subsystem Devices
- Lines
- Tankage
- Umbilicals
- Kits

crew-imposed loads resulting from inadvertent impact and/or from the operation of crew aids (i.e., tether rings, straps, foot restraints, etc.).

Examples of mounting interfaces can be found in Section 2.0. Design guidelines governing crew-imposed loads are outlined in Section 5.0.

6.3 Umbilical/Connector Interfaces

To standardize design interfaces and reduce training and simulation costs, ASE should incorporate the design features and guidelines established in Section 2.0 and Section 3.2.3 (Umbilical Design Guidelines - Expendable Resupply).

6.4 Safety

ASE should be designed to eliminate any potentially hazardous conditions that might endanger the crew and should incorporate protective features such as 'covers' or 'guards' to reduce the potential for inadvertent actuation. General guidelines to ensure a safe operation and activation of ASE are provided in Section 7.0 (Equipment and Crew Safety).

6.5 Mechanisms

Mechanical devices incorporated into ASE are typically classified as either retention systems, articulation systems, actuation systems, or separation systems. These systems can be either motor-actuated or manually driven. Design guidelines governing these systems are presented in Section 4.0 (Mechanical Elements).

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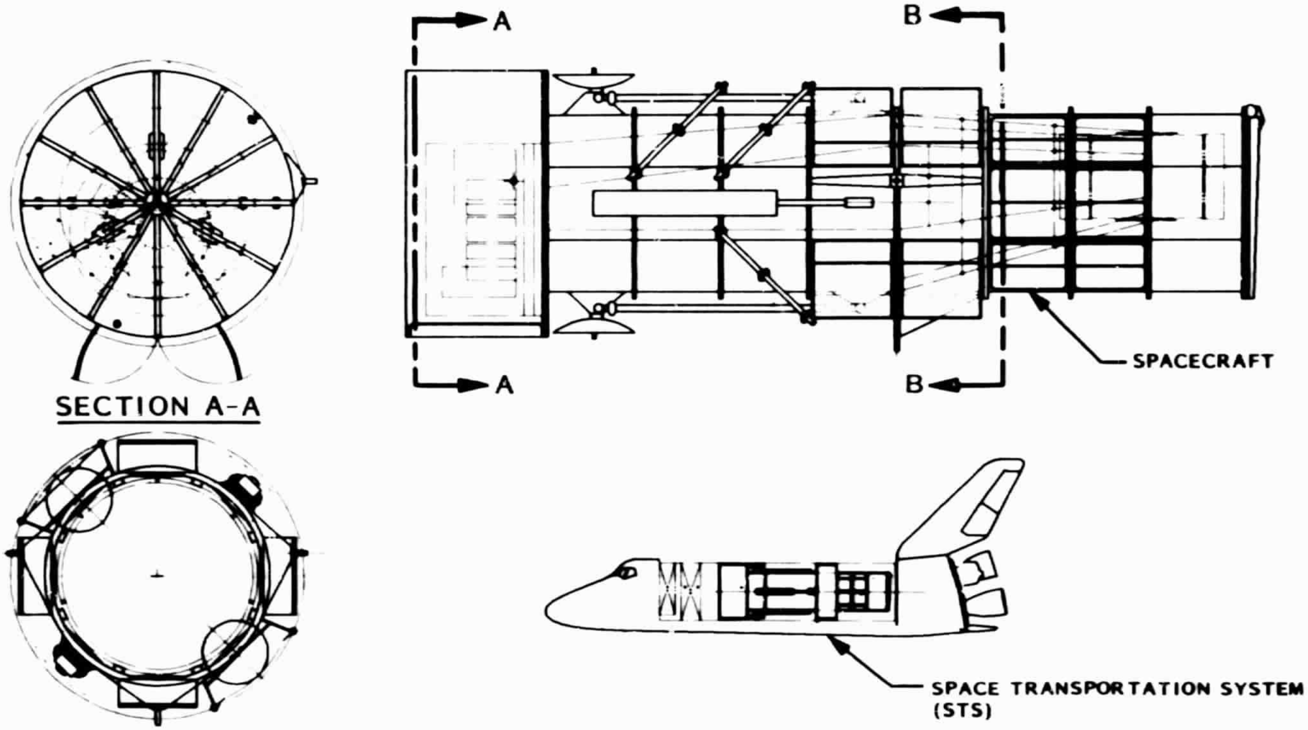
SECTION 7.0
EQUIPMENT AND CREW SAFETY



SECTION A-A

SECTION B-B

7.0 EQUIPMENT AND CREW SAFETY

7.1 General

Spacecraft, payload systems/structures, translation routes, aids, tools and worksites should be designed to eliminate conditions which are potentially hazardous to the crew and to prevent inadvertent actuation of equipment. Equipment should be designed to preclude occurrence of the following: (1) conditions that would allow single point failures to damage equipment, thereby requiring the use of emergency procedures, and (2) conditions that would allow two failures and/or operator errors to occur that could result in crew injury or loss of life. Under no circumstances should the design or operation of equipment prevent the safe return of the Orbiter to ground.

7.2 General Safety Factors

The following guidelines are a compilation of general design features that should be considered in systems to ensure the safety of the crew and spacecraft equipment.

7.2.1 All spacecraft using the Space Transportation System (STS) are required to comply with the safety regulations governing their contractual requirements.

7.2.2 Spacecraft should be designed to ensure that crew safety will not be compromised at any time during normal or unscheduled modes of operation.

7.2.3 The spacecraft, or any part or component of the spacecraft, should not endanger the crew in an emergency landing condition.

7.2.4 All payload-mounted and/or portable crew aids and space support equipment (SSE) should be designed to appropriate safety levels and loads criteria as a function of anticipated use.

7.2.5 Payloads should be designed to minimize crew interface with stored energy devices and/or pyrotechnic equipment.

7.2.6 Where mechanical devices are utilized that require stored energy for their operation, the following guidelines should be applied to the design of the system.

- Labels and safety features (i.e., removal tabs, locks, protective devices, or warning placards) should be incorporated into the design.
- Devices should provide a means for the release of stored energy devices without generating a backlash force greater than 36 inch-pounds.

7.2.7 Payload equipment sensitive to EVA crewmember effluent discharge should incorporate the following protective measures:

- Provide self-protective design features or protective covers installed by the crewmember
- Define operational constraints.

7.2.8 Latches, levers, cranks, hooks and controls that can catch EV-related equipment should be designed and located to prevent gaps, overhangs, and/or snags. In addition, over-center latches (suitcase type) should be designed to prevent inadvertent actuation.

7.3 Operational Safety Considerations

The following guidelines are operational constraints that affect the safety of the crewmember and associated equipment. The guidelines are general in nature; specific areas of concern can be addressed within the STS documentation and/or by the program office, mission integrating support contractor, or JSC program integration team.

7.3.1 During periods of high solar activity, EV activities should be minimized as much as possible.

7.3.2 When possible, a "buddy system" should be employed during EV activities.

7.3.3 The "stay out area" (48 inches aft of the Orbiter airlock into the cargo bay) is the space allocated for egress/ingress. Any payload appendage or structure that penetrates this envelope should be removable or jettisonable.

7.3.5 EV tasks should normally be designed for a maximum of 5.5 hours with a contingency factor of approximately 10 percent.

7.3.6 Foot restraints, handholds, and tether attach points should be provided, as applicable, at all work sites.

7.3.7 The EV crewmember should be tethered at all times.

7.3.8 Surface temperature of components should be compatible with the touch temperature limits defined in Section 2.1.3.6.

7.3.9 Uncovered holes or openings that allow an EV finger access depth to 0.75 inch or greater and that are round or slotted in the range of 0.75 inch to 1.50 inches should be avoided or guarded.

7.4 Crew Impact Damage Prevention

To prevent crew impact damage, the following guidelines should be considered.

7.4.1 Payload equipment layout and location should permit selection of crewmember translation paths which avoid inadvertent damage to equipment. Equipment located along crewmember translation paths should (in descending order of preference):

- Withstand crewmember work forces and inadvertently imposed loads (i.e., handles, tethers, harnesses, connectors, bolt installation torques, wing-tab connectors) as defined in Section 5.4
- Be protected by safety devices
- Include warning devices
- Require special training and safety procedures.

7.4.2 To prevent damage to the spacecraft, proper work clearances, visibility envelopes, and procedural controls should be provided for all crewmember operations.

7.4.3 Protection should be provided to prevent accidental operation of any equipment exposed to crewmember operations.

7.4.4 Shields or covers should be provided for nonruggedized equipment to protect against damage and/or to prevent accidental activation/deactivation of equipment by an EVA crewmember.

7.4.5 Exposed fasteners, securing pins, snap rings, splines, safety wires and elements of other devices used to secure items should be designed and installed as follows:

- Fastening devices/elements should be located to minimize the potential for snagging, tearing, or abrading the extravehicular mobility unit (EMU), crew support equipment, and safety equipment.
- Screws or bolts with more than two exposed threads should be provided with a technique to protect against sharp threads.

- Fastener heads should preferably face the side having the potential for crew tool interface.

7.5 Electrical Safety Considerations

The following guidelines are suggested as methods and techniques to protect the crew and equipment from electrical hazards.

7.5.1 The location of electrical safety controls should permit ready physical access by the crew, allow crewmembers to clearly distinguish ON/OFF positions, and be protected to prevent inadvertent operation.

7.5.2 Payload equipment should be designed to provide electrical grounding from equipment case to payload structure following on-orbit changeout.

7.5.3 Connector pins should be protected from damage at all times, except during changeout operations. Male connector pins should be located on all newly designed equipment changed out on-orbit.

7.5.5 EVA connectors should have power removed before manual disconnect.

7.5.6 Loose EVA connectors/cables resulting from connector release in preparation for appendage jettison should be restrained prior to jettison clamp release.

7.6 Safety Factors in Multilayered Insulation (MLI) Utilization

When MLI is utilized, consideration should be given to the guidelines provided in Section 1.5.

7.7 Equipment or Structure Surface Safety Factors

The structural surface guidelines of Section 1.4 should be applied to prevent damage to the crew and equipment.

7.8 Equipment Safety Tethering

Spacecraft equipment should incorporate the following tethering techniques.

7.8.1 All payload equipment handled or transferred on-orbit by a crewmember should have provisions for tethering.

7.8.2 System and equipment design should minimize the possibility of an item drifting into an inaccessible area where retrieval by a crewmember is not possible.

7.8.3 Equipment greater than 15 inches long should have identifiable nonslip handling features to prevent loss of control during EVA operations.

7.8.4 Tethers, transfer lines, and control lines should be designed and secured to prevent inadvertent snagging of crewmembers and equipment.

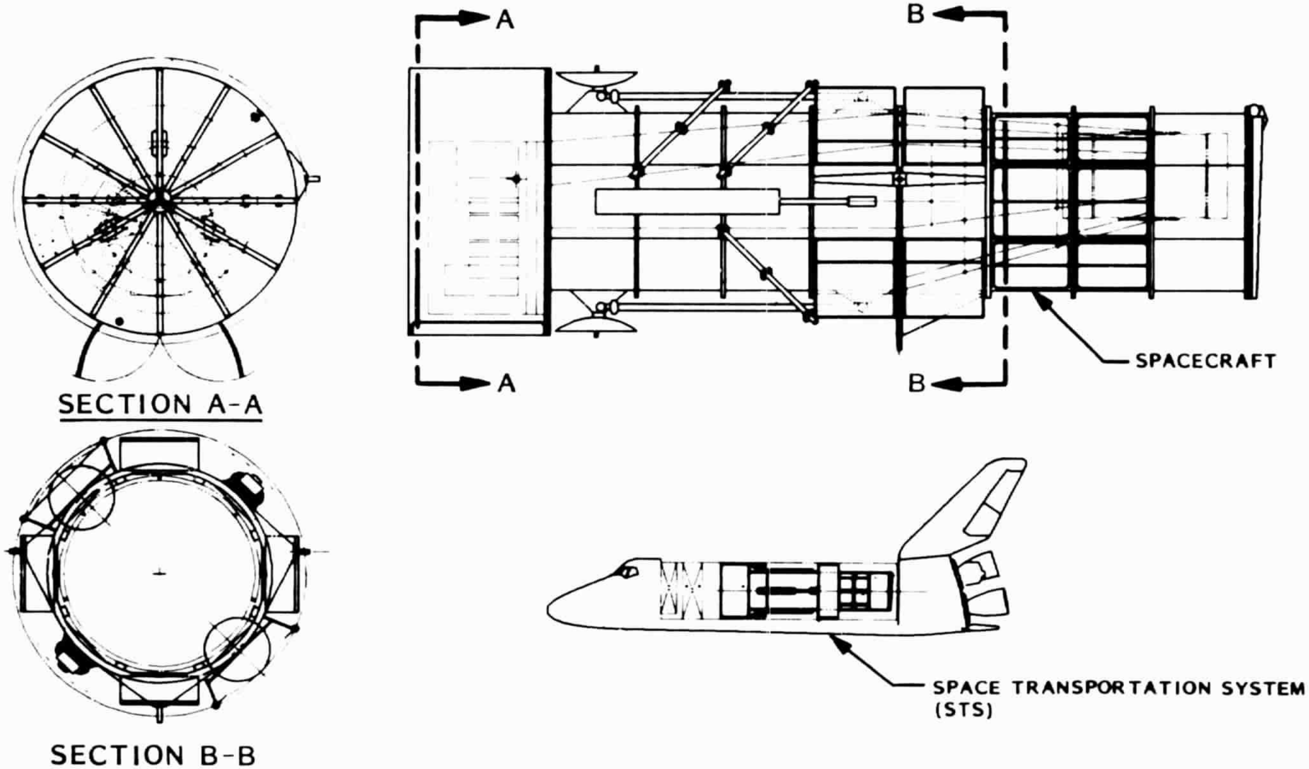
7.8.5 Tether attach points should be located as close to the equipment's center of gravity as possible.

7.9 EV Crew Load Safety Factors

Equipment design requiring EV crewmembers to push-pull, ratchet, turn, rotate, or lift should follow the general guidelines set forth in Section 5.4.

SECTION 8.0

TRAINING, SIMULATION AND ASSOCIATED FACILITIES

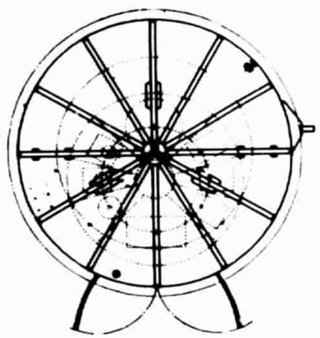


8.0 TRAINING, SIMULATION AND ASSOCIATED FACILITIES

This section is included to direct the satellite designer's attention to the above interface design considerations. This section will be completed in the future.

Lockheed

SECTION 9.0
SOFTWARE



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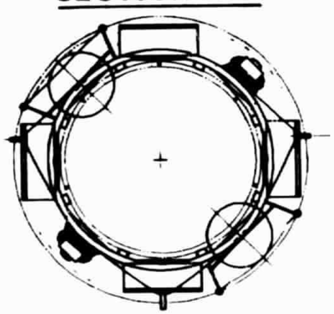

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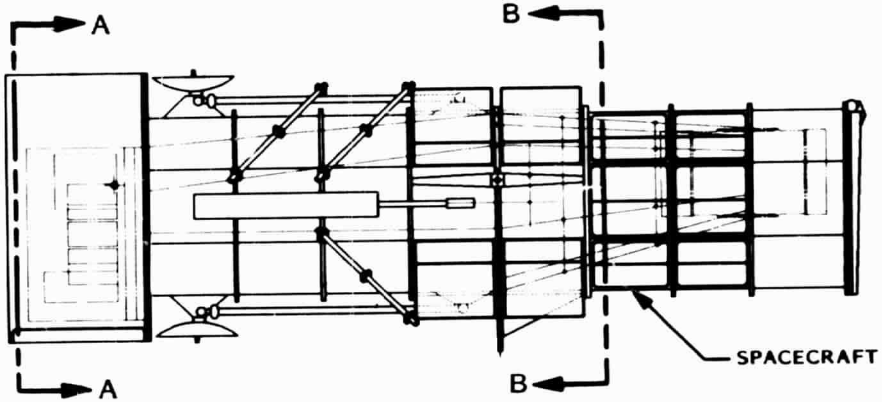

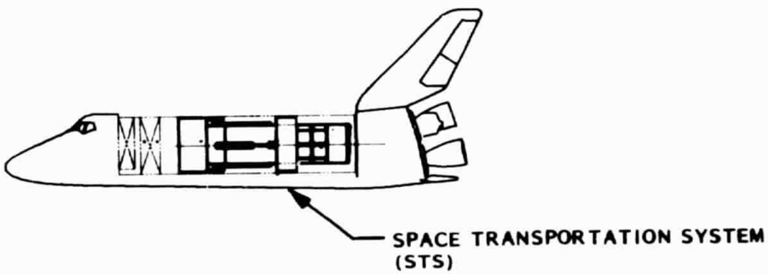

9.0 SOFTWARE

This section is included to direct the satellite designer's attention to the above interface design considerations. This section will be completed in the future.

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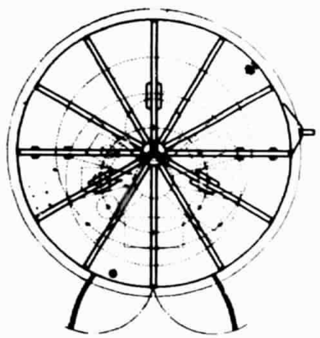
SECTION 10.0

SPACE TRANSPORTATION SYSTEM



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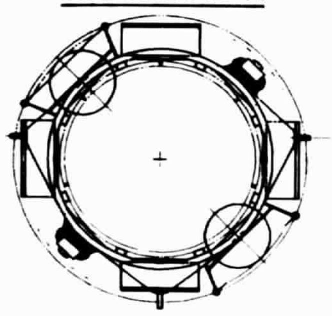

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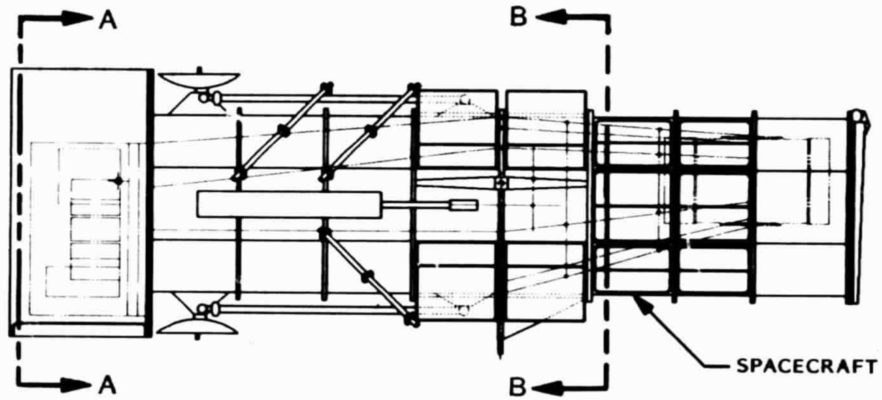
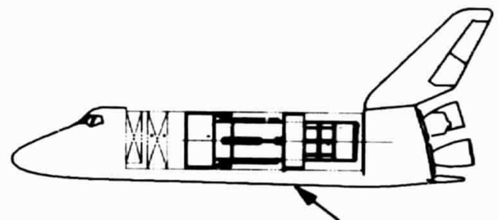


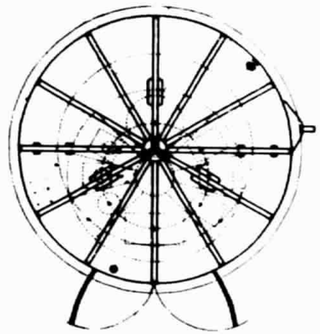


SPACE TRANSPORTATION SYSTEM (STS)

10.0 SPACE TRANSPORTATION SYSTEM

This section is included to direct the satellite designer's attention to the above interface design considerations. This section will be completed in the future.

SECTION 11.0
OPERATIONS



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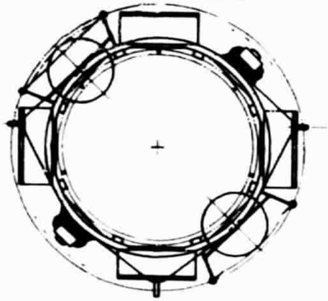

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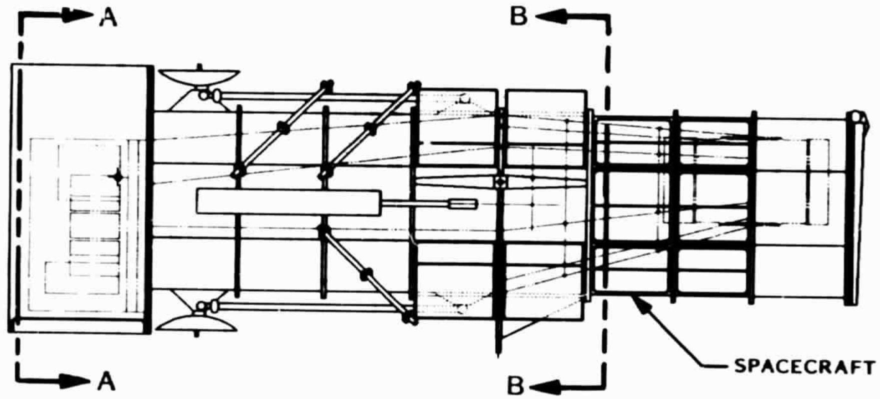

11.0 OPERATIONS

This section is included to direct the satellite designer's attention to the above interface design considerations. This section will be completed in the future.

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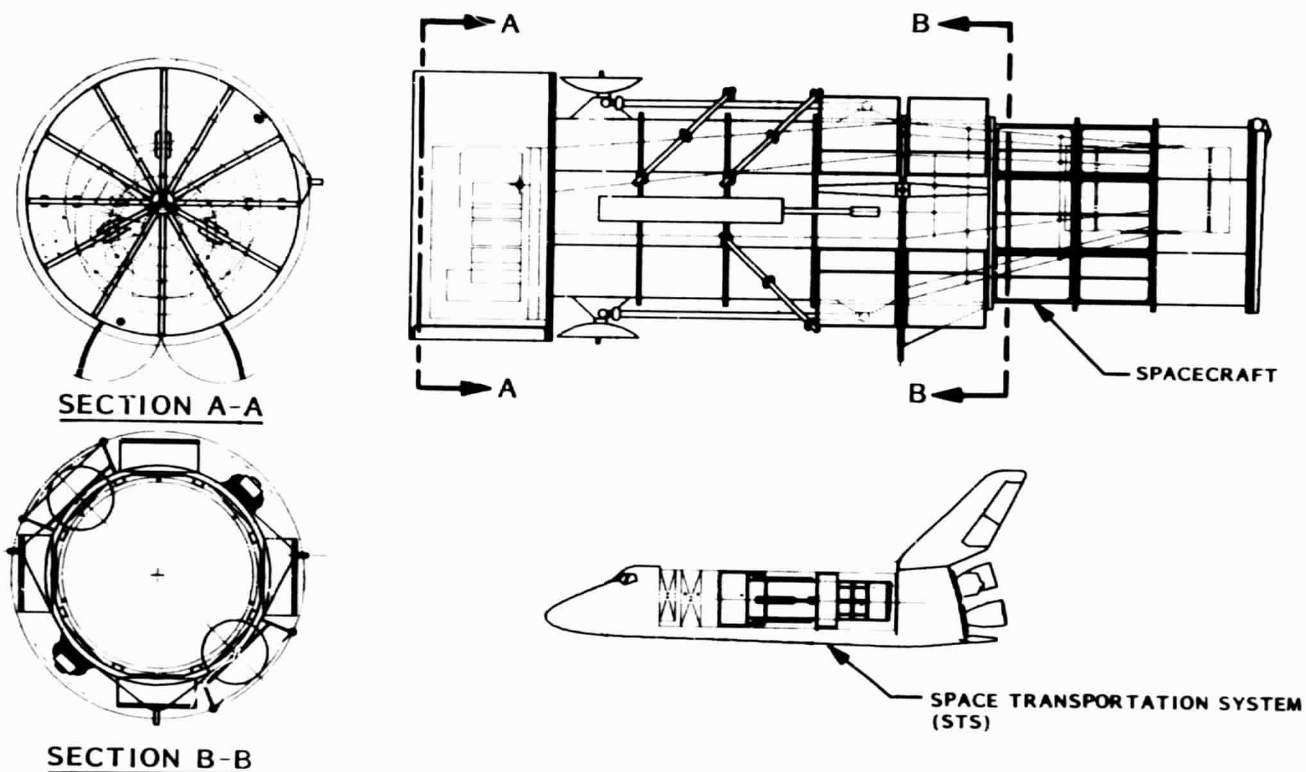
SECTION 12.0
REFERENCES



12.0 REFERENCES

1) Crew Station Specifications, NASA-JSC-07387B, Spacecraft Design Division, Johnson Space Center, Jan. 1982.

2) Design Considerations for On-Orbit Servicing, Satellite Services Workshop, NASA-JSC, June 1982, H. T. Fisher, LMSC.

3) Flight Data File EVA Checklist OV102, NASA-JSC-17325, Flight Operations Division, Johnson Space Center, Basic Revision I, Oct. 1982.

4) Human Engineering Design Criteria for Military Systems, Equipment and Facilities, DoD MIL-STD 1472C, May 1981.

5) Human Engineering Guide to Equipment Design, Joint Army-Navy-Air Force Steering Committee, 1972.

6) Man/System Requirements for Weightless Environments, NASA-MSFC-STD 512A, Man/System Integration Branch, Marshall Space Flight Center, Nov. 1976.

7) Manned Spacecraft Criteria and Standards, NASA-JSCM 8080, Criteria and Standards Board, Johnson Space Center, Change 9, Feb. 1980.

8) Manned Spaceflight Payload Activities Plan (MSPAP), Section 2, PE35171F-PMP500, 6 Oct. 1981.

9) Military Space Systems Technology Model, AIAA Man-in-Space Systems Panel Report, Chairman, Stacy R. Hunt, Sept. 1982.

10) Military Space Systems Technology Model, USAF/AIAA Man-in-Space Systems Panel Report, H. T. Fisher, Deputy Chairman, LMSC, 21 Sept. 1982, Kirtland, AFB, Albuquerque, NM.

11) Orbital Replacement Units, Design Memo, LMSC DM: EQ/I-001, LMSC, Space Systems Division, Space Telescope Project, April 1979.

12) Safety Policy and Requirements for Payloads Using STS, NHB1700.7A, Dec. 1980.

13) Satellite Services Catalog, Tools and Equipment, NASA JSC-19211, Research and Engineering Directorate, Program Development Office, Johnson Space Center, Sept. 1983.

14) Satellite Services System Analysis Study, LMSC-D613709, Volume 1, Technical Proposal, LMSC, Mar. 1980.

15) Shuttle EVA Description and Design Criteria, NASA JSC-10615, Crew Training and Procedures Branch, Johnson Space Center, May 1976.

16) Shuttle Flight Operations Manual, Volume 12, Crew Systems, NASA-JSC 12770, Flight Operations Directorate, Crew Training and Procedures Division, Johnson Space Center, Basic PCN-4, Sept. 1982.

17) Shuttle Flight Operations Manual, Volume 15 EVA Systems, NASA-JSC 12770, Flight Operations Directorate, Crew Training and Procedures Division, Johnson Space Center, Basic PCN-4, Jan. 1981.

18) Space Human Factors, Volumes 1 and 2, NASA-HQ, Workshop Proceedings, 24-26 Aug. 1982, Leesburg, VA.

19) Space Shuttle System Payload Accommodations, Shuttle Orbiter/Cargo Standard Interfaces, NASA-JSC-07700, Volume XIV, including Attachment (ICD2-19001), Rev. H, Change 41, July 1983.

20) Space Station Technology Workshop Symposia, NASA-Langley,, 27-31 Mar. 1983, Various Panel Reports (Document Publication Date TBD as of 4 Apr 1983).

21) Space Telescope/EVA Design Requirements, EM C/0-207A, LMSC, Space Systems Division, Space Telescope Program, May 1981.

22) Space Transportation System, EVA Description and Design Criteria, NASA JSC-10615, Revision A, Crew Training and Procedures Branch, Johnson Space Center, May 1983.

23) System Development Hardware Design Memoranda, LMSC-D710746, LMSC, Space Systems Division, Space Telescope Project, May 1979.

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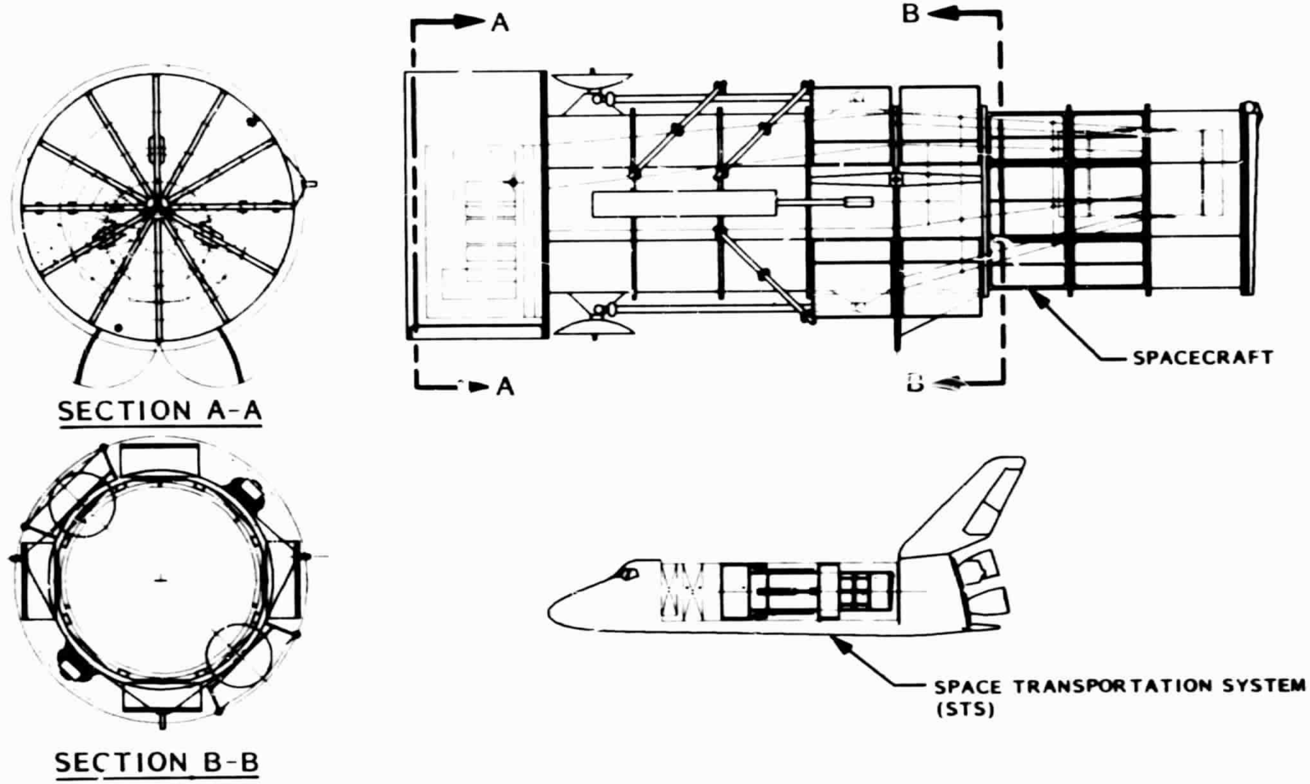
SECTION 13.0

ABBREVIATIONS AND ACRONYMS



13.0 ABBREVIATIONS AND ACRONYMS

AD	aperture door
ASE	airborne support equipment
CCTV	closed circuit television
DoD	Department of Defense
EMU	extravehicular mobility unit
EV	extravehicular
EVA	extravehicular activity
FMEA	Failure Modes and Effects Analysis
GEO	geosynchronous Earth orbit
GFE	Government-furnished equipment
HEO	high Earth orbit
HGA	high-gain antenna
HPA	holding and positioning aid
I/F	interface
IV	intravehicular
IVA	intravehicular activity
MLI	multilayered insulation
MMU	manned maneuvering unit
OMV	orbital maneuvering unit
ORU	orbital replaceable unit
OTV	orbital transfer vehicle
PFR	portable foot restraint
PIDA	payload insertion deployment aid
PLSS	primary life support system
PRLA	payload retention latch actuator
PTS	propellant transfer system
P/L	payload
RMS	remote manipulator system
SA	solar array
SOP	secondary oxygen pack
SSE	space support equipment
STS	Space Transportation System
S/C	spacecraft

DESIGN ELEMENT FACTORS / SECTION NUMBERS	ACCESS DOOR 'KEEPERS'	ALIGNMENT FEATURES	ASE TYPES	CABLING	C&W INDICATORS	DISPLAYS & CONTROLS	EDGE, CORNER, RADII	ELECTRICAL POWER CONSIDERATIONS	FASTENERS & ATTACHMENT SYSTEMS	FOOTPRINT MARKINGS/MOUNTINGS	GROUNDING CONSIDERATIONS	HA
1.0 GENERAL GUIDELINES	1.3.2 1.3.4				1.3.5		1.4.1			1.2.1 1.2.5		
2.0 DESIGN OF ORU'S		2.3.2		2.8				2.8 2.9	2.5	2.3.1	2.9	
3.0 EXPENDABLE RESUPPLY		3.2.3	3.2.2		3.2.1	3.2.1		3.2.1 3.2.3 3.2.4 3.2.5 3.2.7				3.2.7
4.0 MECHANISMS								4.2				
5.0 DESIGN FOR CREW I F	5.4.9 5.4.17	5.4.5		5.4.14	5.8.4.2	5.4.13 5.8.3.4 5.9.3		5.4.3 5.8.4.1				5.6.1 5.7 1 5.8.2 5.9.2 5.10.[illegible]
6.0 AIRBORNE SUPPORT EQUIPMENT			6.1					6.2.3		6.2.2		
7.0 EQUIPMENT AND CREW SAFETY				7.4.1	7.4.1	7.4.1	7.7	7.2 7.5	7.2		7.5	
8.0 TRAINING, SIMULATION & ASSOCIATED FACILITIES												
9.0 SOFTWARE												
10.0 SPACE TRANSPORTATION SYSTEM	TBD											
11.0 OPERATIONS												

T TABLE

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SPACECRAFT HARDWARE DESIGN FACTORS

...NS	...RDWARE DESIGN FOR JETTISON CONSIDERATIONS	LABELING MARKING AND COLOR CODING	LIGHTING, ILLUMINATION AND VISIBILITY	MECHANICAL DEVICES GENERAL	MECHANISMS OPERATIONS EV REQUIREMENTS	MECHANISMS SAFETY	MECHANISMS TYPES	ORU MOUNTING	ORU PACKAGING	REMOTE RESUPPLY EVA CONSIDERATIONS	REMOTE RESUPPLY SAFETY	RESUPPLY PROXIMITY	STRUCTURE SURFACE FINISH	THERMAL INTERFACE CONSIDERATIONS	UMBILICAL DESIGN	CAB...
		1.6.3		1.6		1.6.1		1.3.7					1.4	1.4.1 1.5	2.4.1 2.8	
				2.4.1.10 2.6	2.8.1			2.4.1.13	2.2 2.4.2 2.1.4.11				2.10	2.13	3.2.3	
										3.2.5	3.2.7	3.2.1.1				3.2.3 3.2.4
				4.1	4.3	4.3.4	4.2									
2	5.5.3.2	5.9	5.6										5.4.12		5.4.3	5.4.14 5.4.18
					6.5	6.4		6.2.2	6.2.2						6.3	6.2.3
					7.2	7.2							7.7	7.6		

CHAPTER HEADINGS vs SERVICING GUIDELINE REFERENCE PARA...

SPACECRAFT SERVICING FACTORS

...URFACE / ...ERMAL INTERFACE CONSIDERATIONS	UMBILICAL DESIGN	CABLING MANAGEMENT	CONNECTORS EV TYPES	CREW AIDS	CREW INDUCED LOADS SAFETY, IMPACT DAMAGE	CREWMEMBER STABILITY & RESTRAINT	CREWMEMBER WORK CONSTRAINTS	CREWMEMBER ANTHROPOMETRICS	CREWMEMBER WORK ENVELOPES	EVA TIME CONSTRAINTS	EV HANDLES, KNOBS	GLOVED HAND CONSTRAINTS	INADVERTENT LOADS	LABELING, MARKING AND COLOR CODING	LIGHTNING, ILLUMINATION AND VISI...	OP...
.1 5	2.4.1 2.8				1.5.7			1.3.3 1.5.7				1.5.3				
3	3.2.3		2.6 2.8.2	2.11							2.4.2	2.4.1 2.4.2.3 2.7.7 2.13.6				
		3.2.3 3.2.4	3.2.3	3.2.6.3												
					4.3.1			4.3.1	4.3.3							
	5.4.3	5.4.14 5.4.18	5.4.3 5.4.14	5.5	5.4.2 5.4.20	5.2	5.5.4	5.4 5.2.2	5.3	5.4.1	5.3.4.1	5.3.4 5.4.15	T5.4.1	5.5.3.4 5.8	5.5.3.5 5.7	
	6.3	6.2.3	6.3	6.2.1				6.2.4								
			7.5		7.4 7.9			7.9		7.3.5	7.2					7.2 7.3

...E REFERENCE PARAGRAPH

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SPACECRAFT SERVICING FACTORS

	EV HANDLES, KNOBS	GLOVED HAND CONSTRAINTS	INADVERTENT LOADS	LABELING, MARKING AND COLOR CODING	LIGHTNING, ILLUMINATION AND VISIBILITY	OPERATIONAL SAFETY CONSIDERATIONS	REMOVE/REPLACE VOLUME	RIGHT & LEFT HAND OPERATIONS	SAFETY TETHERING EQUIPMENT	TOOL INTERFACES	TRANSLATION	WORK FORCE APPLICATIONS
		1.5.3					1.2.4			1.3.1 1.6.1	1.3.6	
	2.4.2	2.4.1 2.4.2.3 2.7.7 2.13.6					2.4.1 2.12			2.4.1.5 2.7 2.8.3		2.5.2.7 2.8
										3.2.6.2		
										4.3.3		
	5.3.4.1	5.3.4 5.4.15	T5.4 1	5.5.3.4 5.8	5.5.3.5 5.7			5.4.11		5.3.5 5.4.16	5.3.1	T5.4 3 T5.4 5
	7.2					7.2 7.3			7.8	7.2	7.8	

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